MUDDY CREEK PROJECT - 2006
Final Report

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Background

Muddy Creek, located in north central Montana near Great Falls, is a tributary of the Sun River. Muddy Creek is 42 miles long and accumulates flow from a 314 square mile drainage area. Muddy Creek is well known as a significant sediment contributor to the Sun River. The Montana State University Extension Water Quality (MSUEWQ) group has studied flow and sediment patterns within Muddy Creek during 2002, 2003, and 2005. The 2002 and 2003 studies looked broadly at the entire Muddy Creek watershed and helped pinpoint areas where follow-up and focus was needed to completely understand sediment and flow patterns in Muddy Creek. The 2005 study took recommendations from 2002 and 2003 studies and focused on three specific areas of Muddy Creek. Those areas were: 1) Muddy Creek itself above the Power gauge, and 2) two tributaries to Muddy Creek - Tank Coulee and MC tributary #1. Additional gauges were added within these areas during 2005. Results from the 2005 study helped more clearly define MC tributary #1 sediment and flow patterns. Yet, while additional monitoring stations helped to better understand flow and sediment patterns in Tank Coulee, there were still significant unknowns in Tank Coulee, specifically above Upper Tank Coulee gauge, where there were no gauges installed. Results from the 2005 study provided insights to flow and sediment patterns in Muddy Creek above Power, yet identified a number of issues not resolved completely. MSUEWQ was asked to continue monitoring efforts in 2006 with intention to build on the 2005 study, refining determinations of sources and amounts of flow and sediment within Tank Coulee and Muddy Creek above Power. In addition, Muddy Creek Task Force requested assessment of flow and sediment coming into Muddy Creek via major tributaries, some of which hadn't been monitored since the 2003 study.

Approach

With help of Sun River Watershed coordinator and Greenfield's Irrigation District (GID) staff, a scoping tour was conducted of upper portions of Tank Coulee in early April of 2006. This scoping trip helped to identify two monitoring sites to add to five monitoring sites established in 2005 on Tank Coulee. In addition to these sites on Tank Coulee, all other monitoring stations on Muddy Creek tributary #1 and Muddy Creek above Power established during 2005 were kept. Additionally, monitoring stations of major tributaries at confluences to Muddy Creek between Gordon and Power (MC trib #2, MC trib #3, Spring Coulee) were reestablished. A total of 21 monitoring sites were established during 2006. Figure 1 shows locations of these sites.

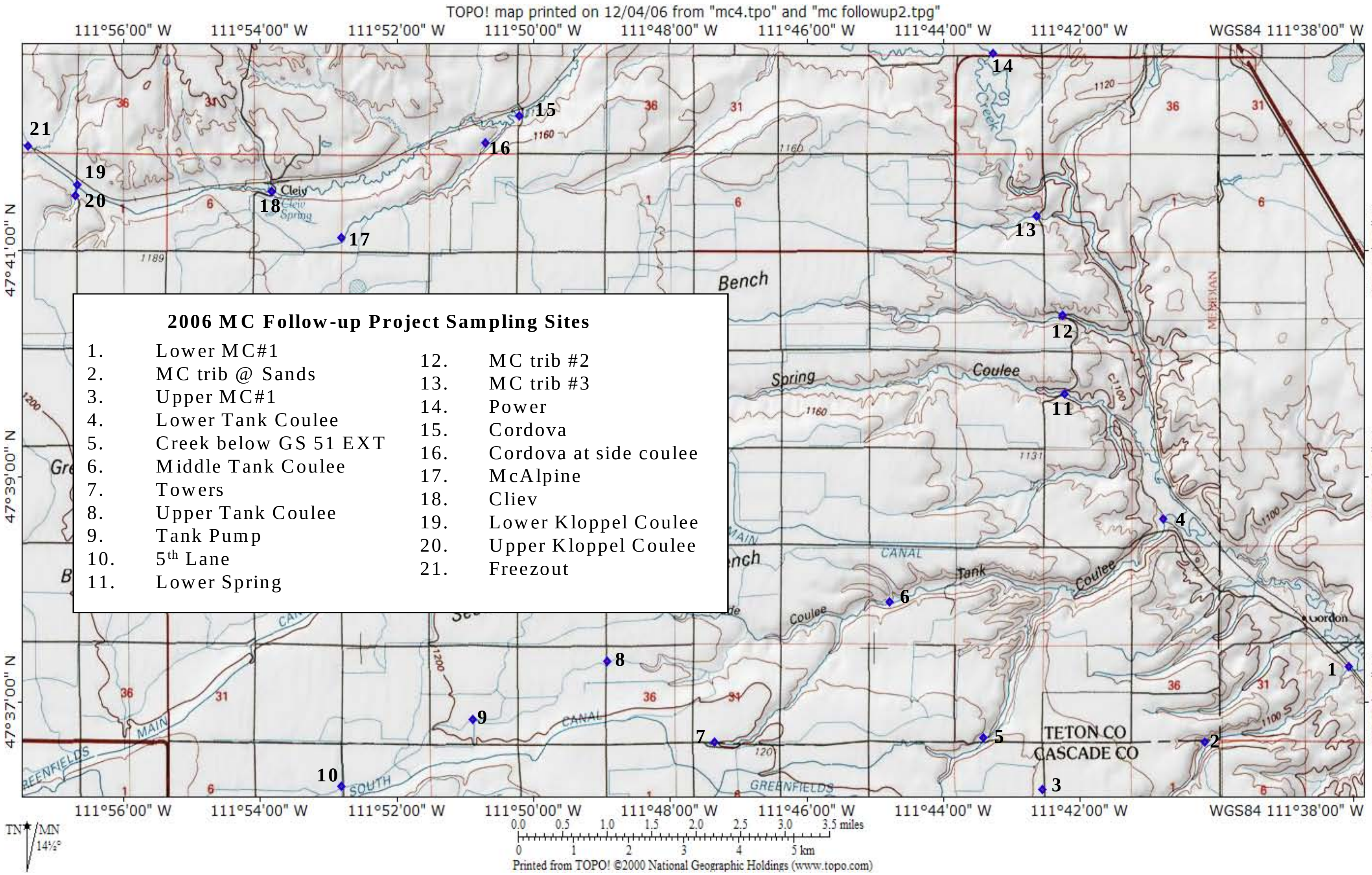


Figure 1. Muddy Creek project 2006 monitoring locations.

An aquarod or tru-track was installed in a stilling well at each of these sites. Aquarods and tru-tracks log water level and water temperature on a continuous basis. Aquarods and tru-tracks were set to record stream stage (water surface elevation) every 30 minutes. Additionally, staff gauges were installed at many of these sampling sites. After initial installation of equipment, each sampling site was visited once before onset of irrigation season, twice a month during the irrigation season, and twice following the irrigation season. Flow was measured during these visits using a Marsh-McBirney Model 2000 Flo-Mate portable flowmeter. Flow measurements made with the flow meter were correlated with aquarod and tru-track stage height measurements to develop rating curves for the water level measurements logged by the aquarods and tru-tracks at each gauging station. In addition, sediment samples were collected during each visit. Sediment samples were put in chilled coolers after collection, then mailed overnight to Montana State University for analysis. Sediment samples were analyzed within seven days from the date of collection.

Flow and sediment data were organized for each gauging station and subsequently used to determine instantaneous flow, time-dependent flow, and average daily flow and daily sediment in tons for each monitoring site for the 2006 irrigation season.

GID started diverting water on May 12 and ceased deliveries on August 12. Thus all calculations made are based on the period between May 12 and August 12, deemed to be the irrigation season.

Efforts were undertaken to define relationships between flow rate (cfs) and sediment concentration (mg/L) at each gauging station. Data collected prior to and after the specific period when water was reportedly being diverted for irrigation purposes (the irrigation season) was used solely for calibration purposes and was not included in calculations of irrigation-season-related flow or sediment. Where appropriate, these data were reported and identified accordingly.

Results

Calculations made were total flow (acre ft), total sediment (tons), sediment concentration (tons/acre ft), and average flow rate (cfs) for the irrigation season, that being the period from May 12 through August 12, 2006 (Table 1). This table is broken down into four different sections of Muddy Creek. Rating curves and flow x sediment concentration curves for each gauging and monitoring station are included within the appendix.

Table 1. Total Flow and Total Sediment for Muddy Creek Tributary #1, Tank Coulee, other Muddy Creek tributaries, and Muddy Creek above Power for 2006 – Irrigation Season (May 12 – August 12).

Station	Source	Total Flow (acre feet)	Total Sediment (tons)	Sediment (tons/acre ft)	Average Flow Rate (cfs)
Muddy Creek Tributary #1					
LMC#1	Aquarod	3,100	476	0.15	17
UMC#1	GID	873	30	0.03	5
MC @ Sands	Tru-track	833	23	0.03	5
Tank Coulee					
LTC	Aquarod	10,437	1,279	0.12	57
MTC	Aquarod	4,352	119	0.03	24
UTC	Aquarod	1,662	27	0.02	9
Tank Pump	Tru-track	4,980	61	0.01	27
5th Lane	Tru-track	3,898	48	0.01	21
Creek below GS 51 EXT	Tru-track	2,186	65	0.03	12
Towers	Tru-track	619	3	0.004	4
Other Muddy Creek tributaries					
Lower Spring Coulee	Aquarod	10,338	1,174	0.11	56
MC#2	Tru-Track	3,466	104	0.03	19
Above Power					
Power	Aquarod/ Tru-track	7,212	501	0.07	39
Cordova	Aquarod	4,682	423	0.09	25
Cordova at Side Coulee	Tru-track	2,460	89	0.04	13
McAlpine	Aquarod	2,025	33	0.02	11
Cliev	Tru-Track	1,822	69	0.04	10
Lower Kloppel Coulee	Tru-Track	712	31	0.04	5
Upper Kloppel Coulee	Tru-Track	996	31	0.03	5
Freezout	Tru-Track	1,015	148	0.14	6

Flow Patterns

Figure 2 shows average daily flows measured at the three stations located in the Muddy Creek tributary #1 drainage. Flow at Upper MC#1 (green line) is in response to GID releases down MC#1. Water only flows past this station during the irrigation season. Flow at the Lower MC#1 (blue line) station tracks the flow in Upper MC#1, but with a significant increase. Some of this increase in flow between these two stations is attributable to a tributary to MC#1, identified as MC trib at Sands (pink line).

Figure 3 depicts average daily flows measured at sampling sites on Tank Coulee. The legend lists stations in order from the most upstream monitoring site (5^{th} Lane) to the most downstream monitoring site (Lower Tank Coulee). Tank Coulee discharges into Muddy Creek just below the Lower Tank Coulee monitoring site. The figure shows that flows at 5^{th} Lane (pink line) and Tank Pump (blue line) monitoring sites track each other, with some increase in flow between 5^{th} Lane and Tank Pump. According to GID personnel, there are quite a few irrigators whose drain and/or return flow water would come into Tank Coulee between these two monitoring stations. On most days, flow at these two stations is greater than flow measured at Upper Tank Coulee (UTC) monitoring site (brown line). GID diverts water out of Tank Coulee just above the UTC gauge (but below the Tank Pump gauge). Average daily flows at UTC, Middle Tank Coulee (MTC), and Lower Tank Coulee (LTC) monitoring sites generally track each other. In a couple of cases within this figure it appears that flow at MTC is greater than LTC, which probably didn't happen. This erroneous flow estimation illustrates that rating curves, while extremely helpful, do have limited accuracy.

There are two noticeable spikes in flow in Tank Coulee in 2006. The first occurred around May 28, and the second spike occurred around June 10. These spikes correspond with rainfall events. The Agrimet station, maintained by the Bureau of Reclamation and located near Fairfield, recorded 1.54 inches of precipitation between 5/27 and 5/28 and 3.88 inches between June 7 and 10. A total of 6.67 inches of precipitation was recorded for the entire irrigation season.

Figure 4 is a plot of daily flows within Muddy Creek at and above the Power monitoring site. The legend lists stations in order from the most upstream site - Lower Kloppel Coulee, which is considered the start or beginning of Muddy Creek, to Power. Flows at monitoring sites above Power generally track each other, and spikes in flow match spikes noted in the Tank Coulee figure (Figure #3), and which were attributable to rainfall events. During the June 10^{th} rainfall event, flows within Muddy Creek increased to well above 100 cfs at the Power monitoring station.

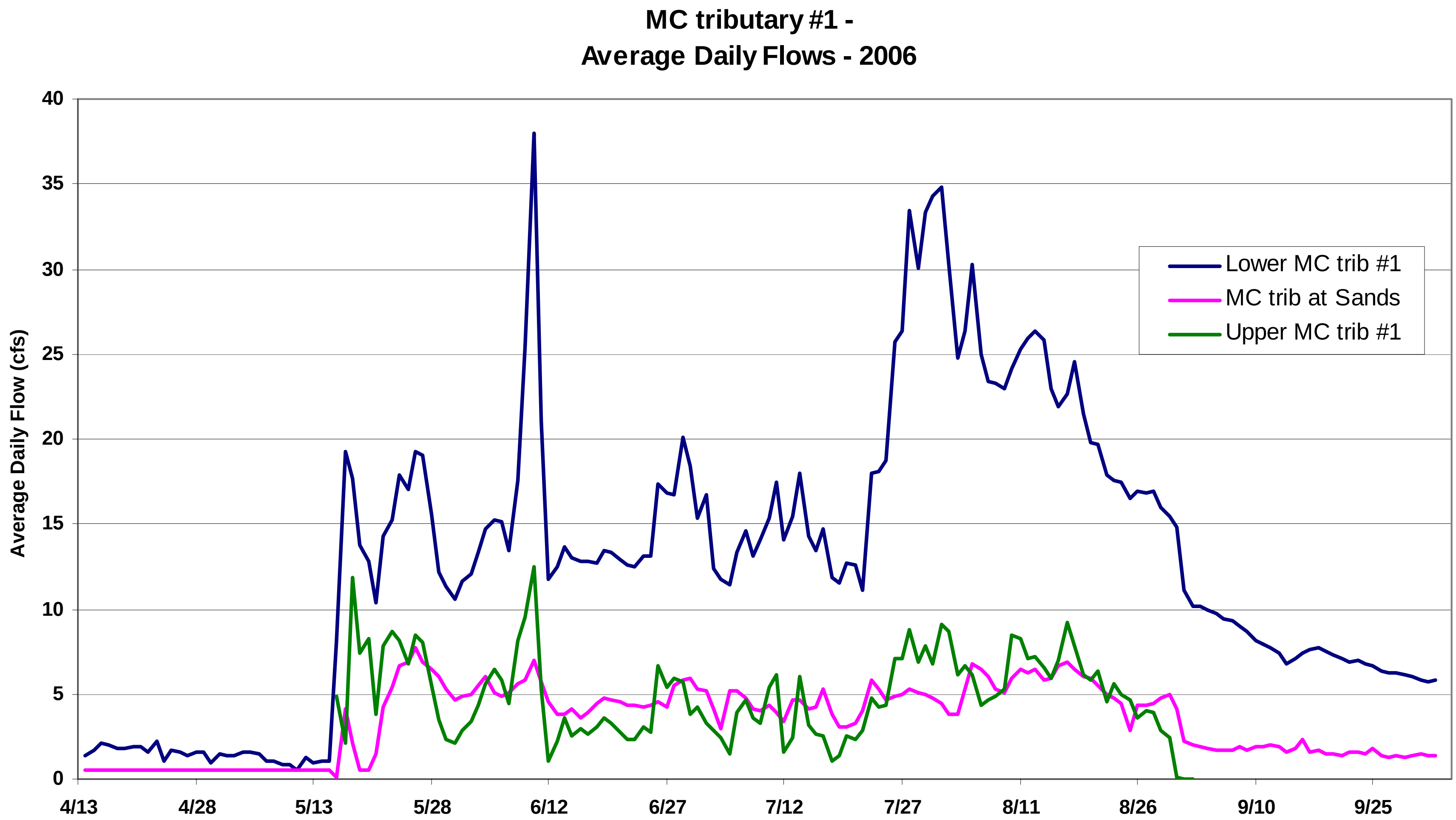


Figure 2. Average daily flows measured within Muddy Creek tributary #1.

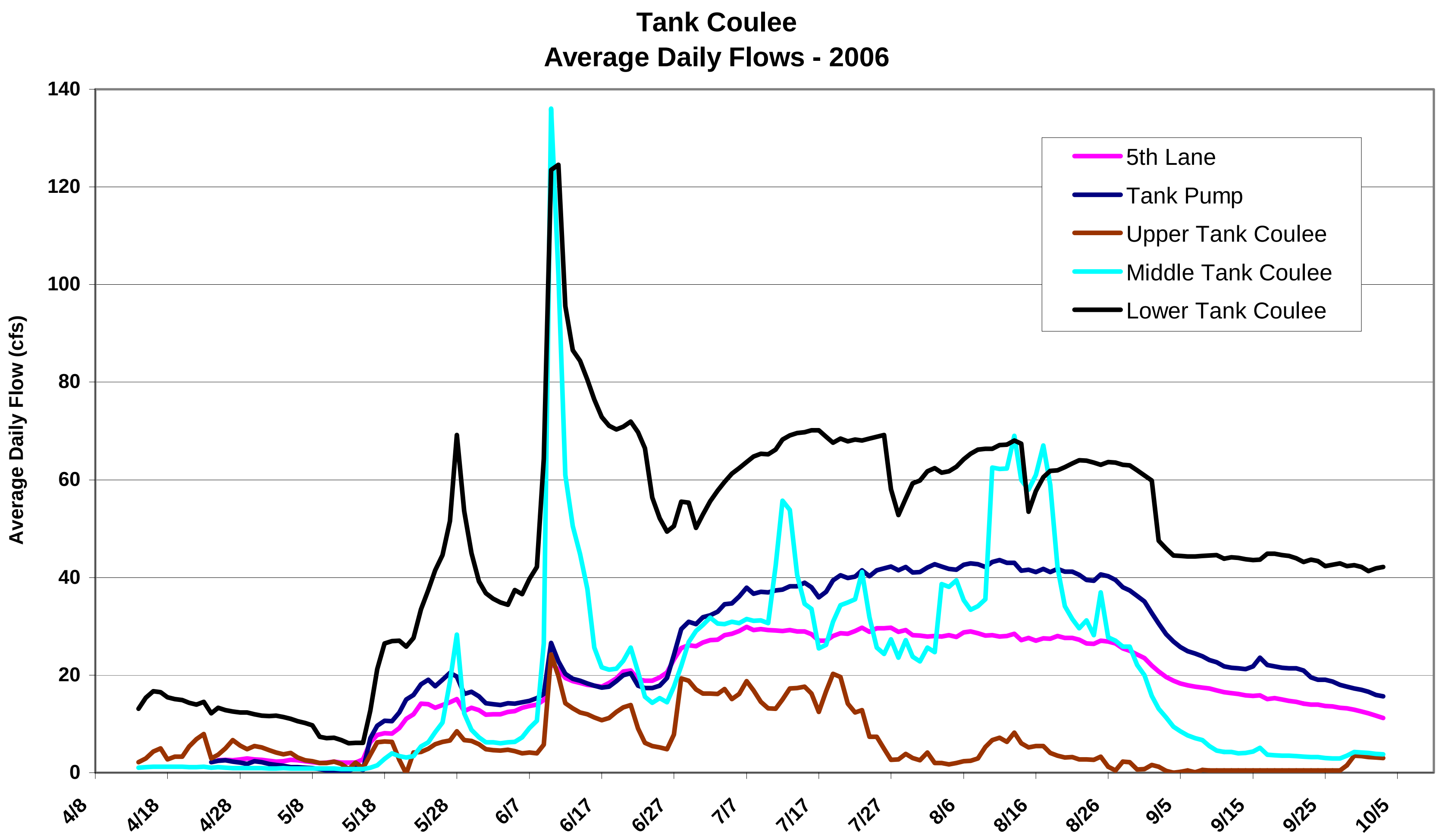


Figure 3. Average daily flows measured within Tank Coulee.

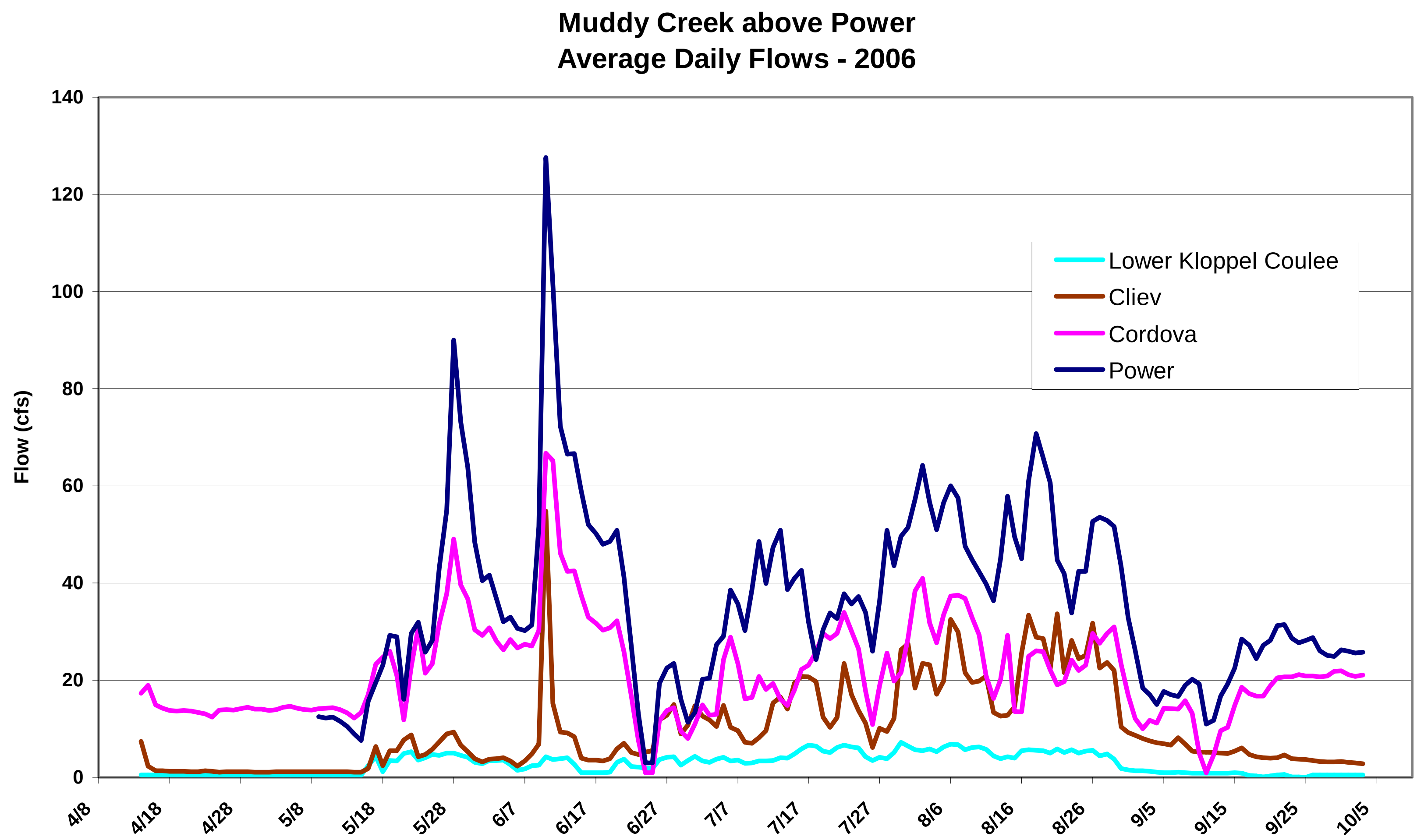


Figure 4. Average daily flows in Muddy Creek at and above the Power monitoring station.

Increases in flow as a function of rainfall are evident in Figures 2 through 4 as spikes in the plots of average daily flows. The largest spike in flow is associated with the Jun 7-10th rainfall event. Table 2 illustrates how this particular rainfall event impacted flows within Muddy Creek and tributaries. Total acre-feet of flow for June 7-10 is calculated for each monitoring station. The percentage of seasonal flow that was measured during this rainfall event was also calculated. Flows during this four-day period accounted for 2 – 8% of the total flow measured during the irrigation season at each monitoring station.

Table 2. Flow measured at monitoring stations during June 7 – 10, 2006, and percentage of irrigation season flow (May 12 – August 12, 2006) that was measured during this rainfall event.

Station	**Flow (acft) – June 7-10**	**Percentage of Total Flow**
Lower MC trib #1	187	6%
MC trib at Sands	47	6%
Upper MC trib #1	69	8%
Lower Tank Coulee	534	5%
Creek below GS 51 EXT	110	5%
Middle Tank Coulee	350	8%
Towers	27	4%
Upper Tank Coulee	75	5%
Tank Pump	144	3%
5th Lane	129	3%
Lower Spring Coulee	654	6%
MC trib #2	115	3%
Power	477	7%
Cordova	299	6%
Cordova at Side Coulee	158	6%
McAlpine	142	7%
Cliev	61	3%
Lower Kloppel Coulee	21	3%
Upper Kloppel Coulee	24	2%
Freezout	29	3%

Flow fluctuations, whether attributable to rainfall or irrigation operations, can cause sediment transport. Fluctuations in flow for each monitoring station were determined for the period of monitoring by calculating standard deviations in flow (cfs) for each 24-hour period. These daily standard deviations were then plotted for the period of irrigation. The magnitude of the standard deviation reflects the 24-hour fluctuation in flow for the monitoring site. This provides a visual means of assessing monitoring stations with extreme fluctuations in flow on a 24-hour period. Figures 5 – 7 show standard deviation in flows during 24-hour periods for each monitoring station.

A list of monitoring stations with large 24-hour standard deviations are: Lower MC#1, Upper MC#1, MC @ Cordova, MC @ Power, and Lower Spring Coulee.

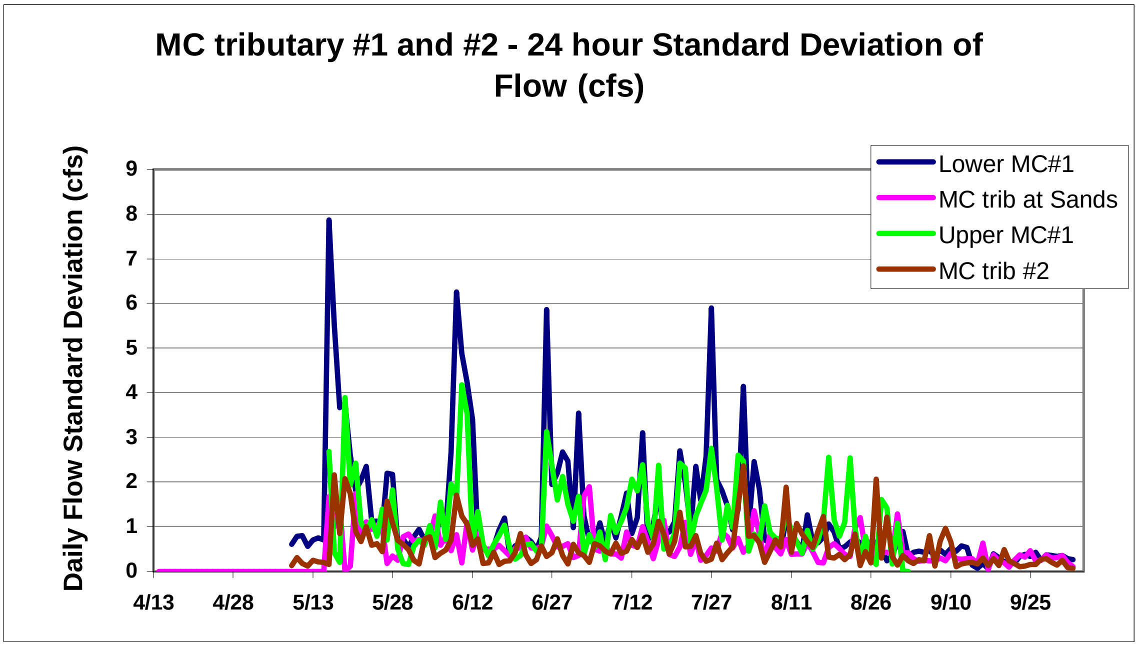


Figure 5. 24-hour standard deviation in flow for MC tributary #1 and #2.

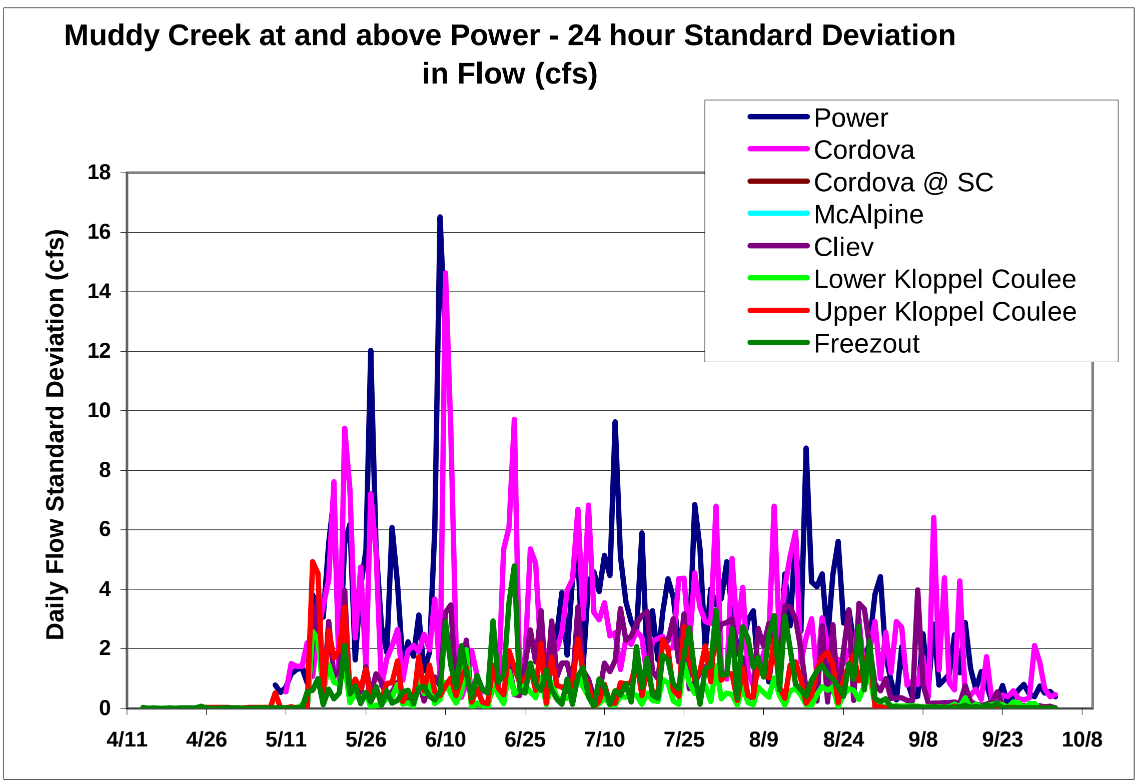


Figure 6. 24-hour standard deviation in flow in Muddy Creek above Power.

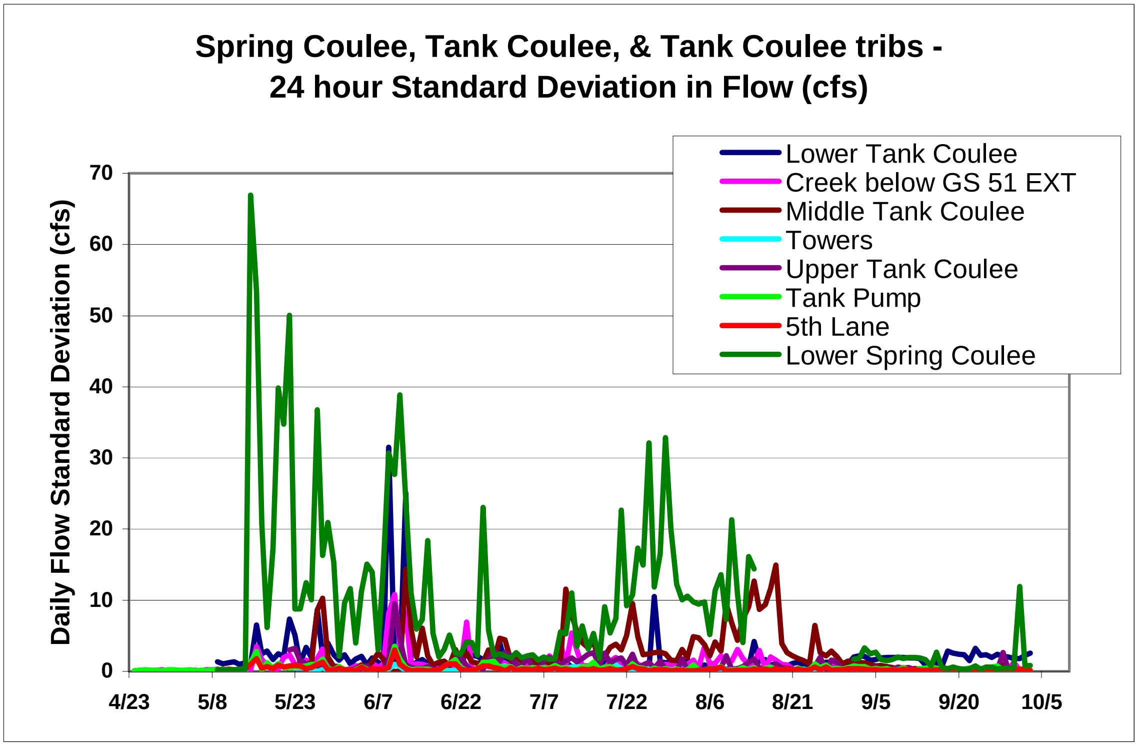


Figure 7. 24-hour standard deviation in flow in Spring Coulee, Tank Coulee, and Tank Coulee tributaries.

Flow and Sediment Patterns

Flow and sediment values measured within the project area are illustrated on Figure 8. Black diamonds identify monitoring stations, while text in brown surrounded by boxes are spills reported by GID. Gains and losses in flow and sediment between monitoring stations are circled and include either a plus "+" signs indicating gains or a minus "-" signs indicating losses in flow and sediment. Additionally, green text serves to identify gains in flow and sediment, while text in red illustrates losses in flow and sediment.

Three monitoring stations were located on Muddy Creek tributary #1. Upper Muddy Creek #1 (UMC#1) marks the start of this tributary. The UMC#1 monitoring gauge is an automated flow station maintained by the Bureau of Reclamation and GID. The gauge records water surface elevation measurements every 15 minutes. Additionally a contributing flow to this stream – MC trib at Sands – was monitored. This tributary averaged a contribution of 5 cfs to MC trib #1 throughout the irrigation season. GID reported two spills, totaling 833 acre-feet, which discharged between the upper and lower gauges on MC trib #1. **The Lower Muddy Creek #1 (LMC#1) gauge recorded the contribution of flow and sediment to Muddy Creek – 3,100 acre-feet and 476 tons during the 2006 irrigation season. There was gain in flow and sediment between the UMC#1 and LMC#1 monitoring stations of 561 acre-feet and sediment of 423 tons.**

Tank Coulee was extensively monitored during 2006. Two new monitoring stations (5th Lane and Tank Pump) helped to better define the source of flow and sediment coming past the UTC gauge. **<u>Nearly 4,000 acre-feet of flow came past the most upstream monitoring gauge (5th Lane).</u>** GID personnel report that water coming into the study area upstream of 5th Lane is mostly drain/return flow water. The irrigation district does spill some water above this station, but GID staff report that it is only a couple of cfs at most. **<u>There is a modest gain in flow, approximately 1,000 acre-feet, between 5th Lane and Tank Pump monitoring stations and only a small gain in sediment (13 tons) between these two stations.</u>** A loss in both flow and sediment is measured between the Tank Pump monitoring site and the UTC monitoring station. GID diverts water out of Tank Coulee between these two stations. Between the UTC and MTC stations a tributary nicknamed Towers, as the gauge is located by the Three Rivers Telephone Company tower, was monitored. This tributary only flows during the irrigation season, and contributed 619 acre-feet of water and very little sediment (3 tons). GID reported a spill of 129 acre-feet between UTC and MTC. **<u>There was also a gain of 1,942 acre-feet and 89 tons of sediment between UTC and MTC.</u>** Another large gain in flow and sediment is measured between the next two stations on Tank Coulee. **<u>A tributary identified as Creek below GS 51 EXT was monitored, and contributed a little over 2,000 acre-feet and 65 tons of sediment to Tank Coulee.</u>** Additionally GID reported a spill of 272 acre-feet between MTC and LTC.

The largest unaccounted for gains in flow and sediment were measured between MTC and LTC. The topography throughout the Tank Coulee watershed is characterized by steep hills, of which the tops are irrigated. It is likely that irrigation of these up-gradient fields contributes a significant amount of drain/return flow water to Tank Coulee.

Two additional tributaries, that hadn't been monitored since 2003, were monitored in 2006 – Lower Spring Coulee (LSC) and Muddy Creek tributary #2 (MC#2). A gauge was also installed on another tributary monitored in 2003 – Muddy Creek tributary #3. A culvert below the Muddy Creek tributary #3 station repeatedly filled with debris during much of the 2006 monitoring season, causing water to back up. The result was unreliable data. Therefore, flow and sediment values were not calculated for this station. **<u>Measurements at LSC revealed this tributary contributed flows of 10,388 acre-feet and sediment of 1,174 tons during the irrigation, similar to amounts measured at LTC. MC#2 contributed slightly more flow, but very little sediment to Muddy Creek than did LMC#1.</u>**

One focus of this study was to expand on the 2005 report, with respect to understanding flow and sediment patterns in Muddy Creek up-stream of Power. A gauge located on Upper Kloppel Coulee defined the top of our study area. Water flowing past this gauge can either be diverted to Muddy Creek, and would subsequently pass the Lower Kloppel Coulee gauge, or it can be diverted to Freezout Lake, and be measured at the monitoring gauge accordingly named Freezout. **<u>Of 996 acre-feet of water measured at the Upper Kloppel Coulee gauge, 712 acre-feet was diverted past Lower Kloppel</u>**

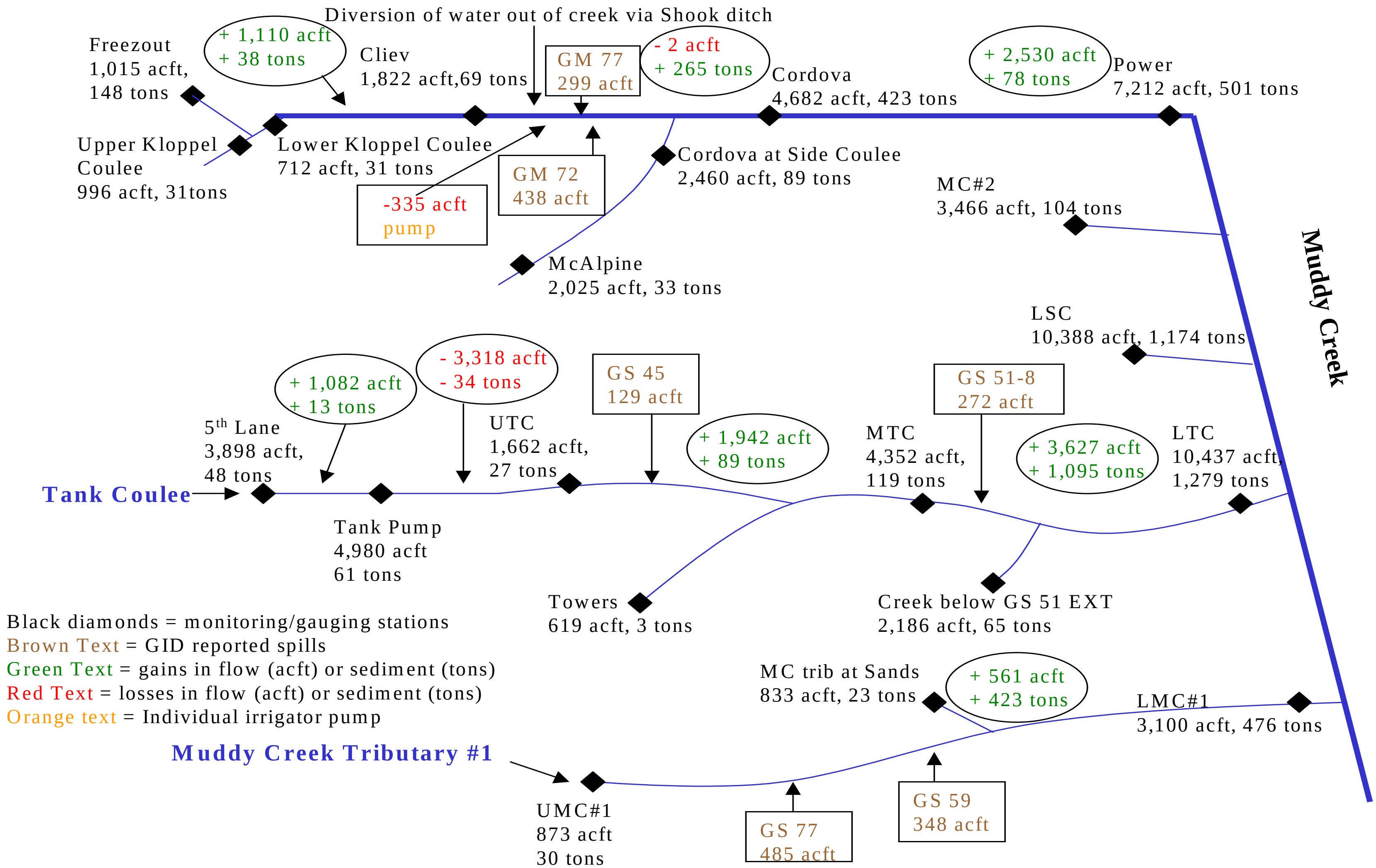


Figure 8. Flow and sediment calculations for Muddy Creek above Power and tributaries.

Coulee monitoring station and into Muddy Creek. The additional water was diverted towards Freezout. Additionally, another coulee discharges in between the Upper Kloppel Coulee and Freezout monitoring stations that contributes a portion of the flow measured at the Freezout monitoring station. **Approximately 1,000 acre-feet of water and 148 tons of sediment were measured going past the Freezout gauge during the 2006 irrigation season.** A significant gain in flow and a modest gain in sediment was measured between the Lower Kloppel Coulee station and the monitoring station at Cliev. According to GID staff, there are several springs within this area of Muddy Creek. This gain in flow and sediment is very similar to the gains between these two monitoring stations measured in 2005. Between Cliev and Cordova, a loss in flow and a gain in sediment were measured. This also occurred in 2005. GID reports two spills that contribute 737 acre-feet between these two monitoring sites. **Additionally, a tributary monitored via the Cordova at Side Coulee gauge was determined to contribute 2,460 acre-feet of flow and 89 tons of sediment to Muddy Creek.** Yet, accounting for these additions of flow, a minimal loss is measured. GID diverts water out of Muddy Creek via the Shook ditch between Cliev and Cordova. Additionally, several irrigators are pumping out of Muddy Creek through this reach as well. One irrigator pumps approximately 814 gallons/minute continuously throughout the season. **A gain in flow and sediment of 2,530 acre-feet and 78 tons, respectively, was measured between Cordova and Power monitoring sites.** A similar gain in flow was measured in 2005 between these two locations, while measurements in 2006 indicated a more modest gain in sediment between these two locations. **A little over 7,000 acre-feet of water and 500 tons of sediment were transported in Muddy Creek past the Power station during the 2006 irrigation season.**

Summary Statistics on Muddy Creek, 2002-2003, 2005-2006

MSUEWQ has worked on defining flow and sediment loads and patterns in Muddy Creek since 2002. Each year, revisions to the sampling plan have been made as lessons learned have helped define additional focus areas. Table 3 is a summary of flow measurements made by MSUEWQ between 2002 and 2006. Table 4 is a summary of corresponding sediment measurements in tons for these same periods. When comparing numbers from year to year, it is important to remember that length of the irrigation season varies. In 2002, values were calculated from May 12th – September 24th. During 2003, values were determined for an irrigation season that ran from May 10th through August 6th. Values calculated for the 2005 irrigation season were calculated from May 12th – August 20th, while the 2006 irrigation season was a few days shorter – May 12th – August 12th.

Table 3. Summary of flow measurements (acre-feet) during 2002, 2003, 2005, and 2006 irrigation seasons in Muddy Creek and tributaries.

Monitoring Station	**2002**	**2003**	**2005**	**2006**
Upper MC trib #1	1,403	746	1,059	873
Lower MC trib #1	3,495	2,595	2,817	3,100
Upper Tank Coulee	2,352	1,638	3,181	1,622
Middle Tank Coulee	NM	4,403	5,231	4,352
Lower Tank Coulee	13,243	8,240	9,911	10,437
Upper Spring Coulee	7,477	5,044	NM	NM
Lower Spring Coulee	13,503	6,836	NM	10,388
MC trib #2	4,209	3,998	NM	3,446
MC trib #3	3,698	2,676	NM	NM
MC @ Power	18,581	6,756	6,212	7,212
MC@ Cordova	NM	NM	3,761	4,682
Cordova @ Side Coulee	NM	NM	3,169	2,460
McAlpine	NM	NM	2,485	2,025
Cliev	NM	NM	1,910	1,822
Lower Kloppel Coulee	NM	NM	695	712
Upper Kloppel Coulee	NM	NM	1,232	996
Freezout	NM	NM	1,247	1,015

*NM – monitoring site not measured.

Table 4. Summary of sediment measurements (tons) during 2002, 2003, 2005, and 2006 irrigation seasons in Muddy Creek and tributaries.

Monitoring Station	**2002**	**2003**	**2005**	**2006**
Upper MC trib #1	127	68	17	30
Lower MC trib #1	312	772	1,142	476
Upper Tank Coulee	210	60	69	27
Middle Tank Coulee	NM	496	177	119
Lower Tank Coulee	1,410	1,695	1,253	1,279
Creek below GS 51 EXT	NM	NM	63	65
Towers	NM	NM	0	3
Upper Spring Coulee	740	777	NM	NM
Lower Spring Coulee	1,205	960	NM	1,174
MC trib #2	373	381	NM	104
MC trib #3	330	257	NM	NM
MC @ Power	4,072	1,308	637	501
MC@ Cordova	NM	NM	625	423
Cordova @ Side Coulee	NM	NM	419	89
McAlpine	NM	NM	10	33
Cliev	NM	NM	83	69
Lower Kloppel Coulee	NM	NM	7	31
Upper Kloppel Coulee	NM	NM	12	31
Freezout	NM	NM	66	148

*NM – monitoring site not measured.

Summary / Conclusions

Twenty in-stream monitoring stations within the Muddy Creek watershed were monitored for flow and sediment during the 2006 GID irrigation season. Two additional monitoring stations were added in 2006 to help understand flow and sediment coming into Muddy Creek above the Upper Tank Coulee gauge. Also, two gauges were installed on tributaries that hadn't been monitored since 2003. Data collected showed:

1. The largest gains in flow and sediment were measured in Tank Coulee between the MTC and LTC monitoring stations.
2. The greatest contributions of sediment and flow to Muddy Creek came from the LTC and LSC monitoring stations.
3. The greatest 24-hour fluctuations in flow were measured at Lower MC#1, Upper MC#1, MC @ Cordova, MC @ Power, and Lower Spring Coulee.
4. Flow and sediment values and respective contributing sources have remained fairly consistent during four years of MSUEWQ sampling.
5. The data collected in 2005 and 2006, when compared with data collected in 2002, suggest that water management changes and institution of irrigation-related BMPs within the watershed may not be having a significant beneficial impact with respect to either flow or sediment over the past five years.

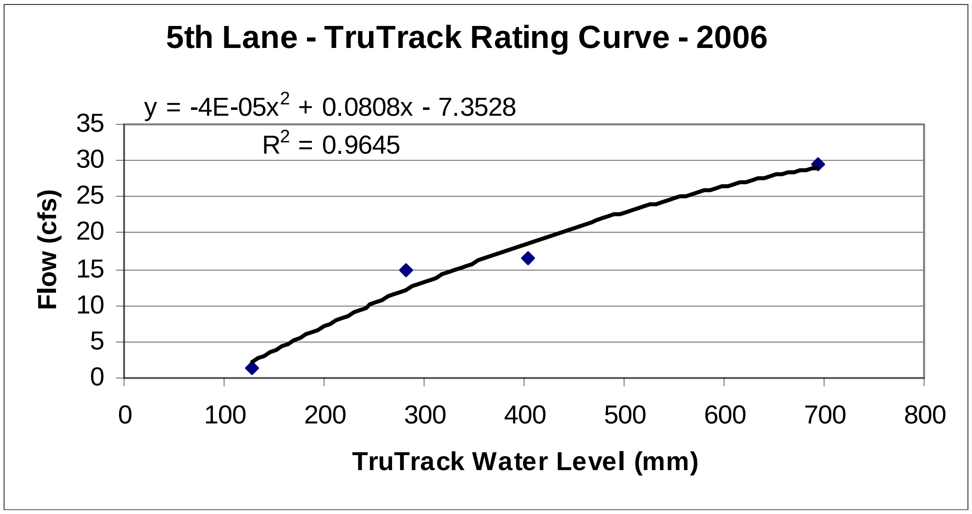
Additionally, the data suggest that the following reaches and associated water management and BMPs be inventoried – in as much as they are the principal contributors of flow and sediment.

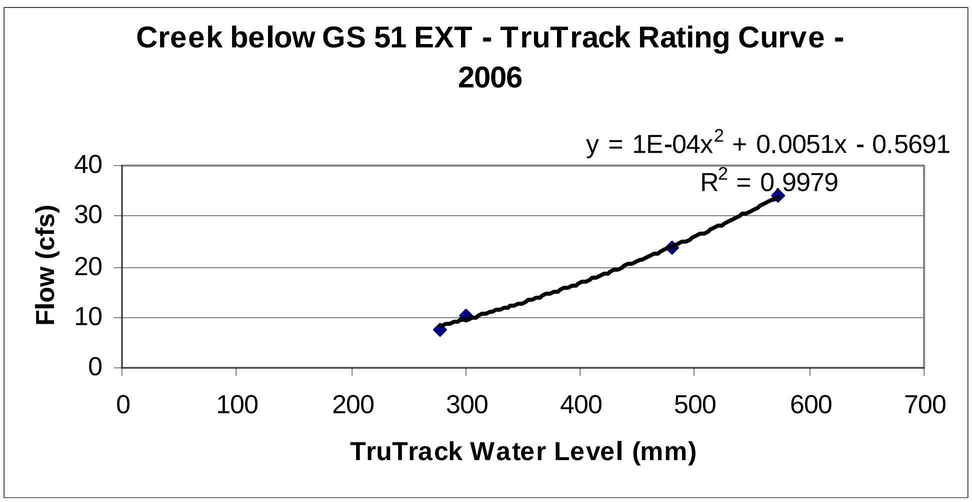
- Upper to Lower Muddy Creek tributary 1 (MC#1)
- Middle to Lower Tank Coulee
- Spring Coulee
- Muddy Creek Cliev to Power with emphasis on Cordova to Power

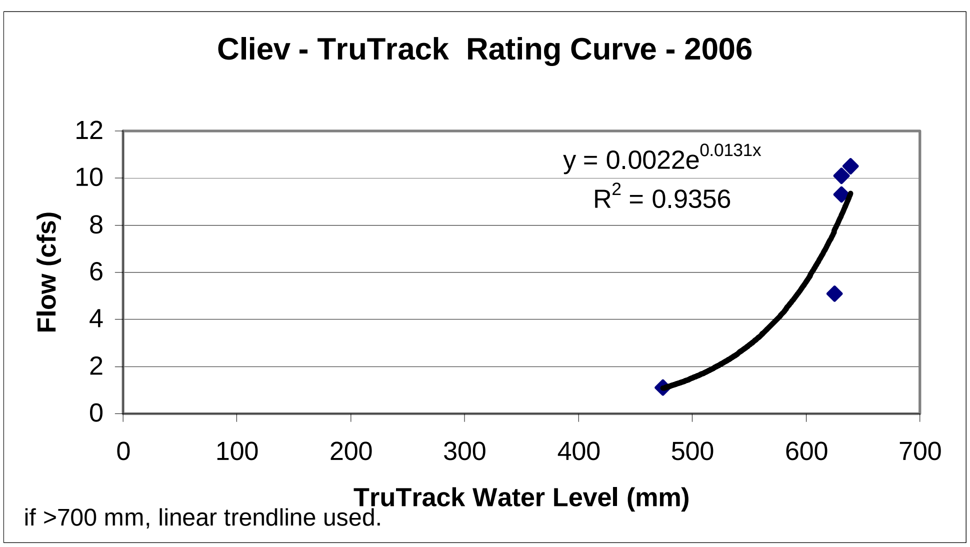
Emphasis should be placed on assessment of "actual" sediment sourcing within each of these reaches, with efforts to distinguish sediment actually sourced from inflows versus sediment sourced from bank and bottom scour and channel erosion. Each of the reaches identified above for additional assessment constitutes a stream reach of significant flow increase from upstream to downstream monitoring stations. Thus, the question yet to be answered is "what is the actual source or cause for increased sediment at the downstream gauging stations?"

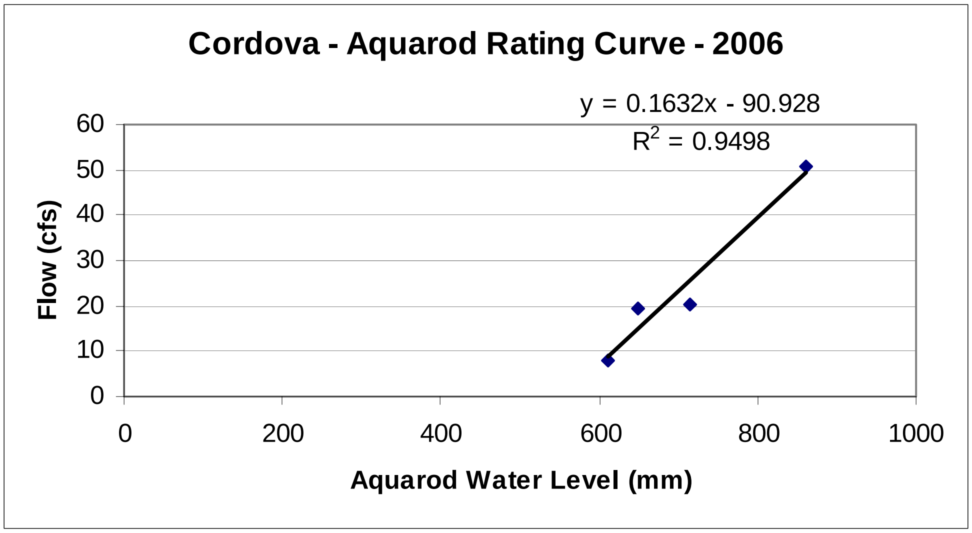
APPENDIX

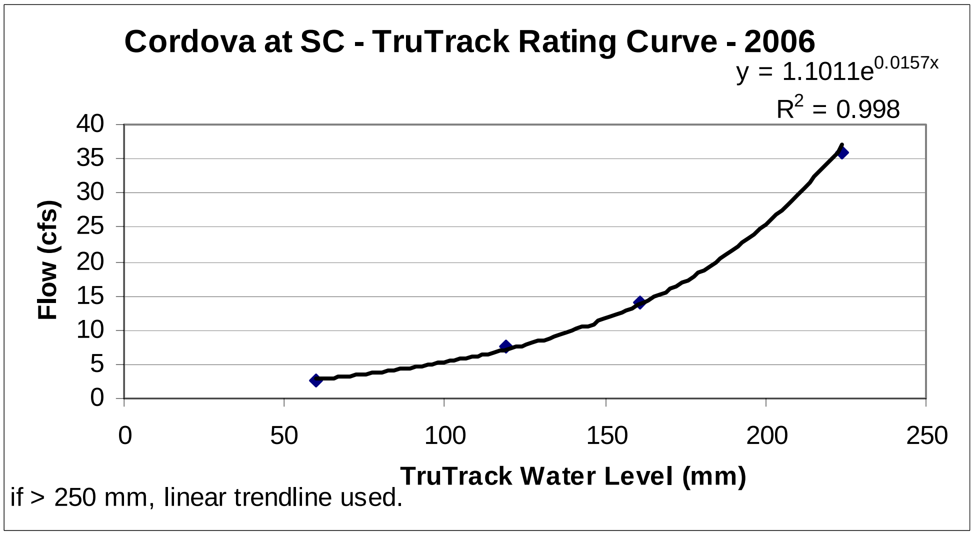
1. Aquarod and Tru-Track Rating Curves

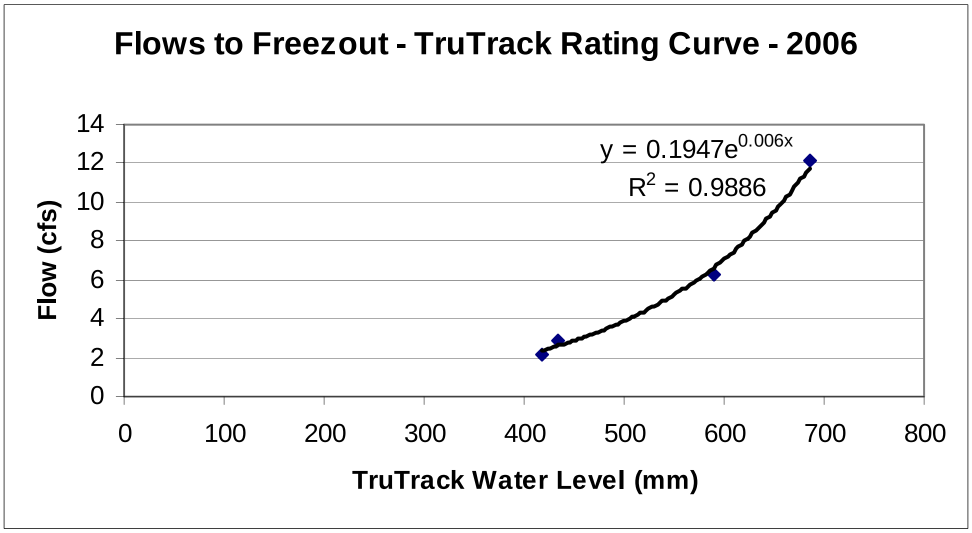


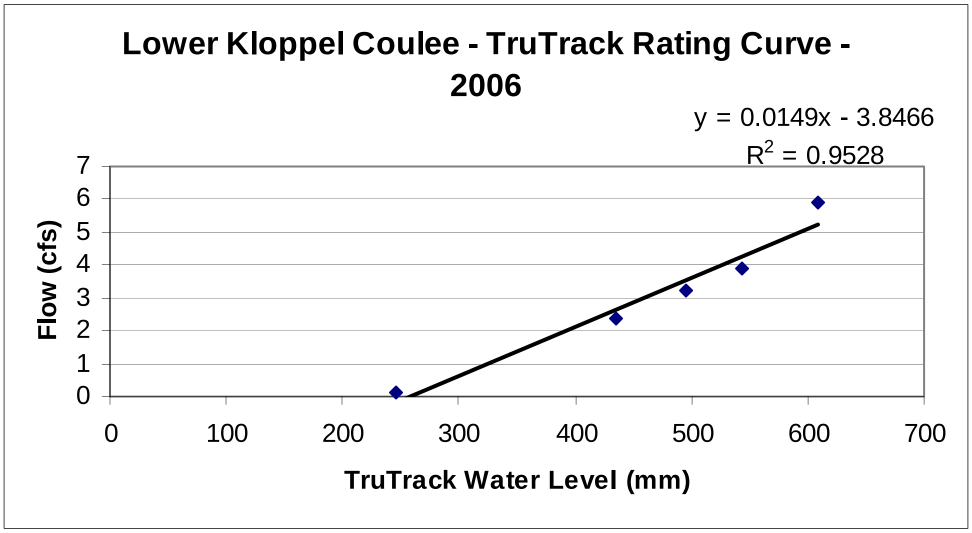


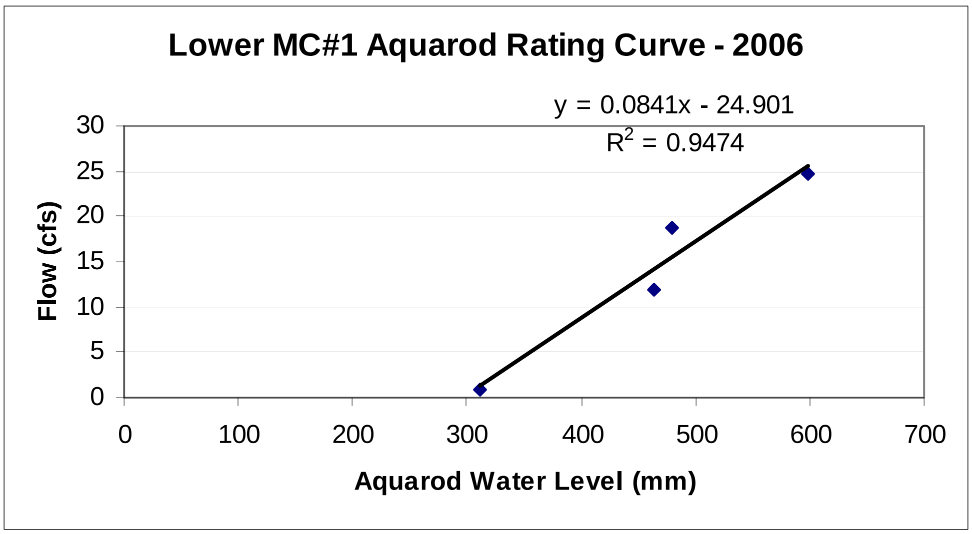


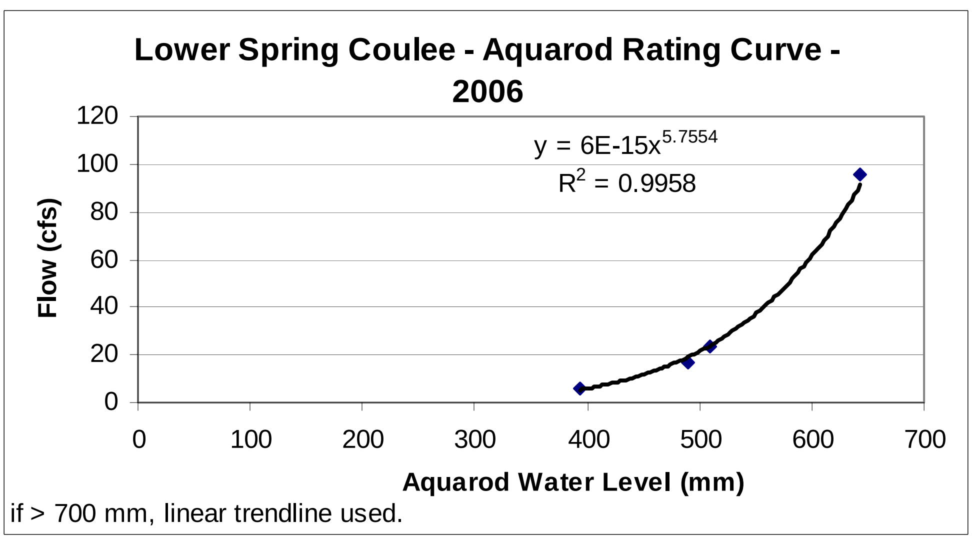

Cordova - Aquarod Rating Curve - 2006
y = 0.1632x - 90.928
R2 = 0.9498
Flow (cfs)
60
50
40
30
20
10
0
0
200
400
600
800
1000
Aquarod Water Level (mm)

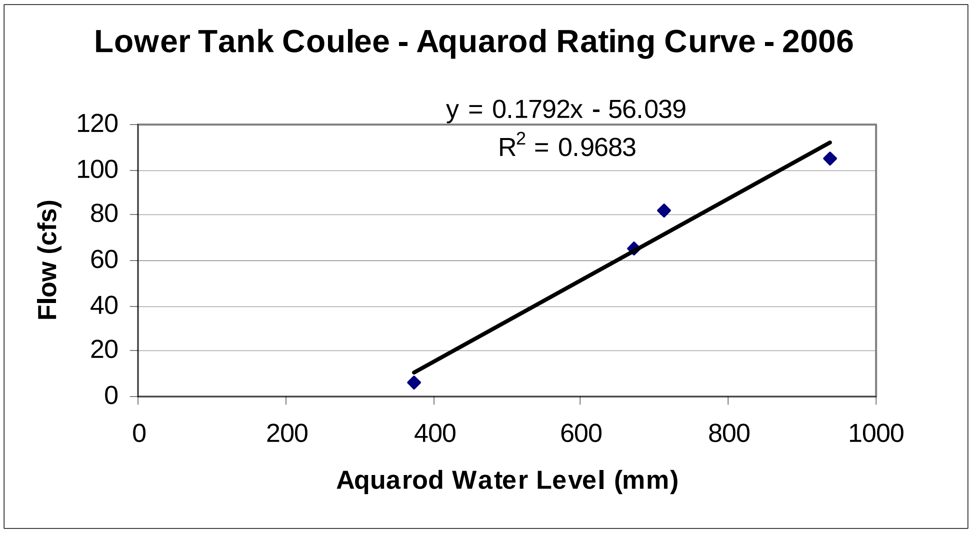

Cordova at SC - TruTrack Rating Curve - 2006
y = 1.1011e0.0157x
R2 = 0.998
Flow (cfs)
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
TruTrack Water Level (mm)
if > 250 mm, linear trendline used.

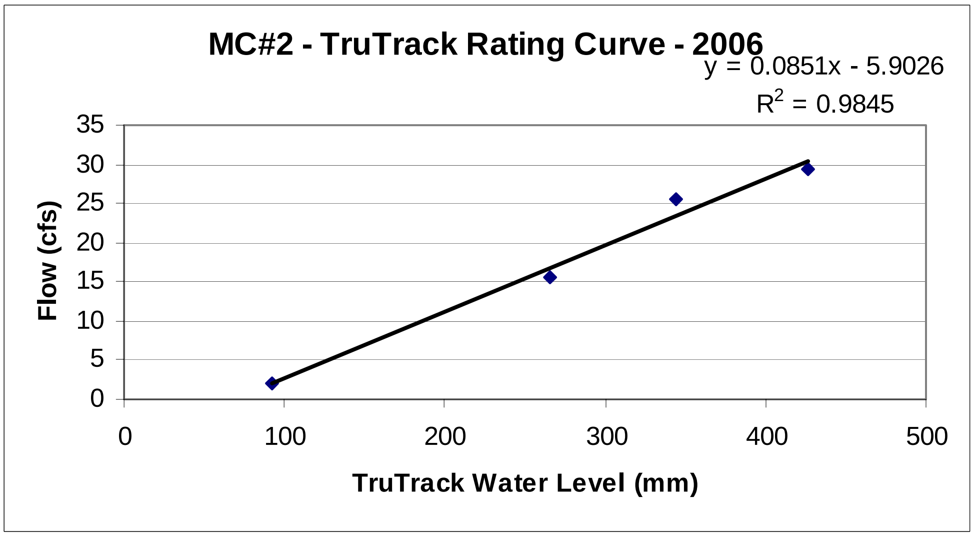

Flows to Freezout - TruTrack Rating Curve - 2006
y = 0.1947e0.006x
R2 = 0.9886
Flow (cfs)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
TruTrack Water Level (mm)

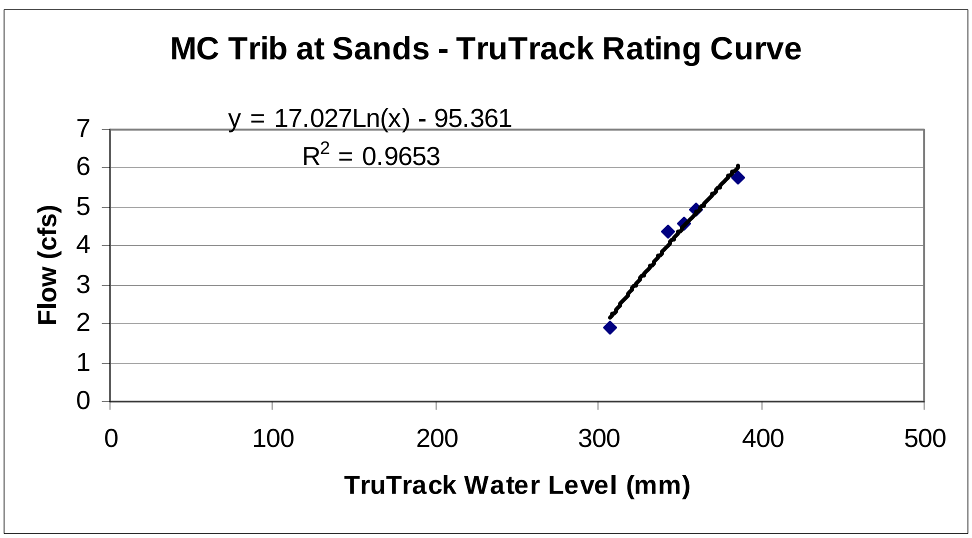

Lower Kloppel Coulee - TruTrack Rating Curve - 2006
y = 0.0149x - 3.8466
R2 = 0.9528
Flow (cfs)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
TruTrack Water Level (mm)

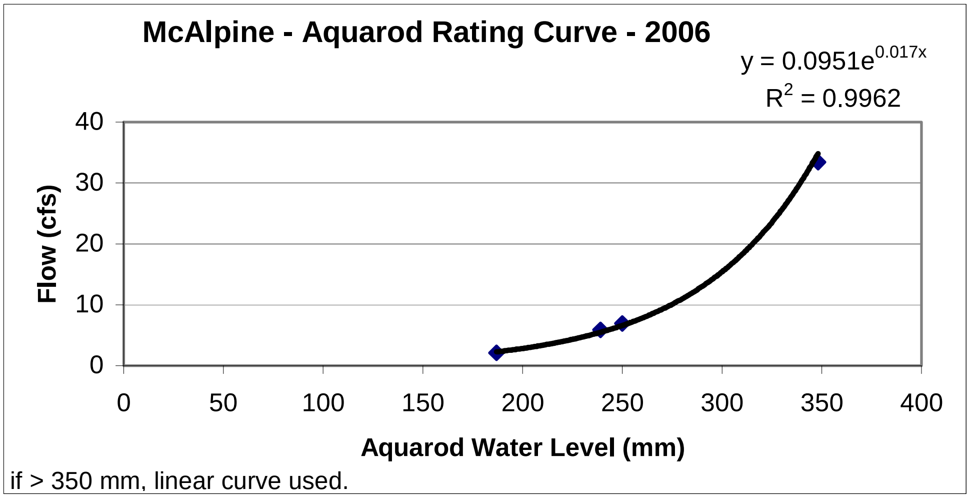

Lower MC#1 Aquarod Rating Curve - 2006
y = 0.0841x - 24.901
R2 = 0.9474
Flow (cfs)
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
Aquarod Water Level (mm)

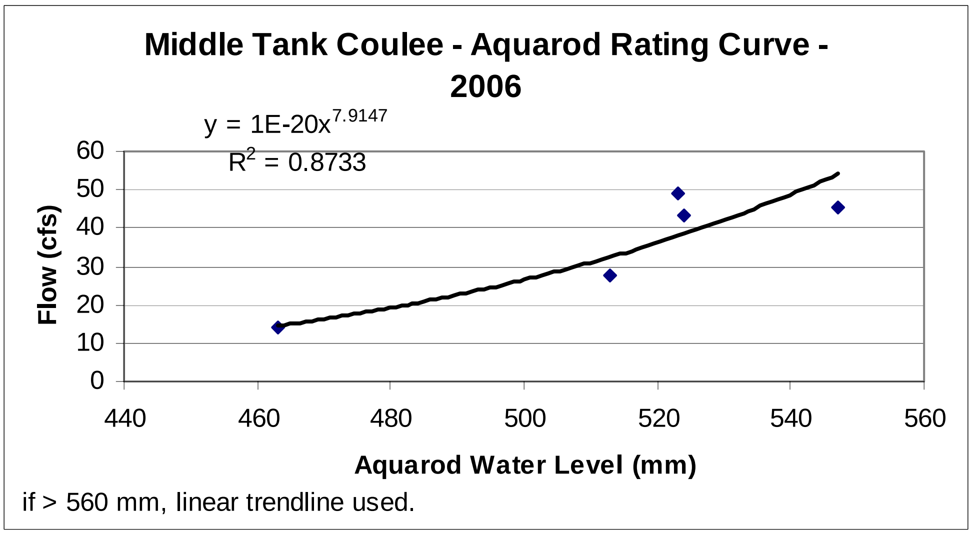

Lower Spring Coulee - Aquarod Rating Curve - 2006
y = 6E-15x5.7554
R2 = 0.9958
Flow (cfs)
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
Aquarod Water Level (mm)
if > 700 mm, linear trendline used.

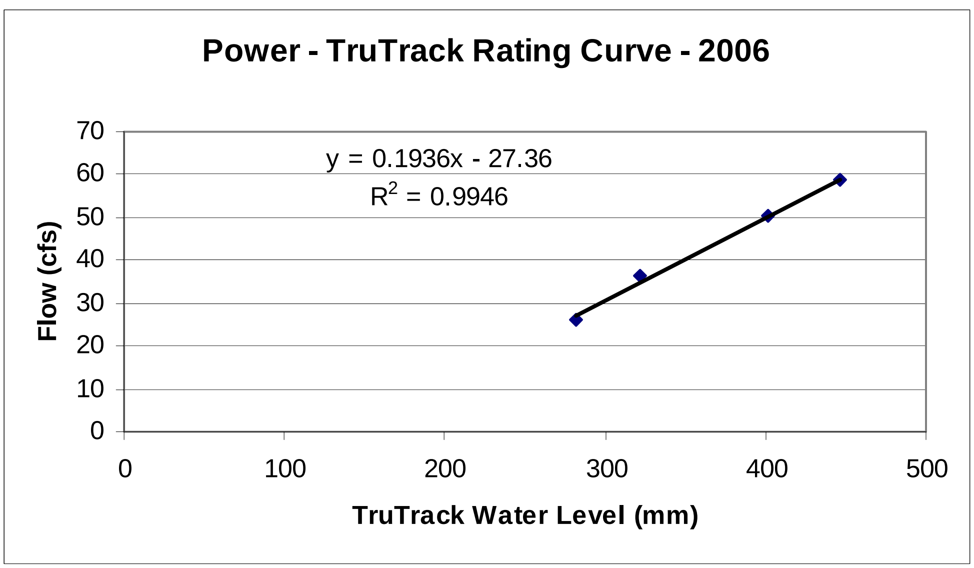

Lower Tank Coulee - Aquarod Rating Curve - 2006
y = 0.1792x - 56.039
R2 = 0.9683
Flow (cfs)
0
20
40
60
80
100
120
0
200
400
600
800
1000
Aquarod Water Level (mm)

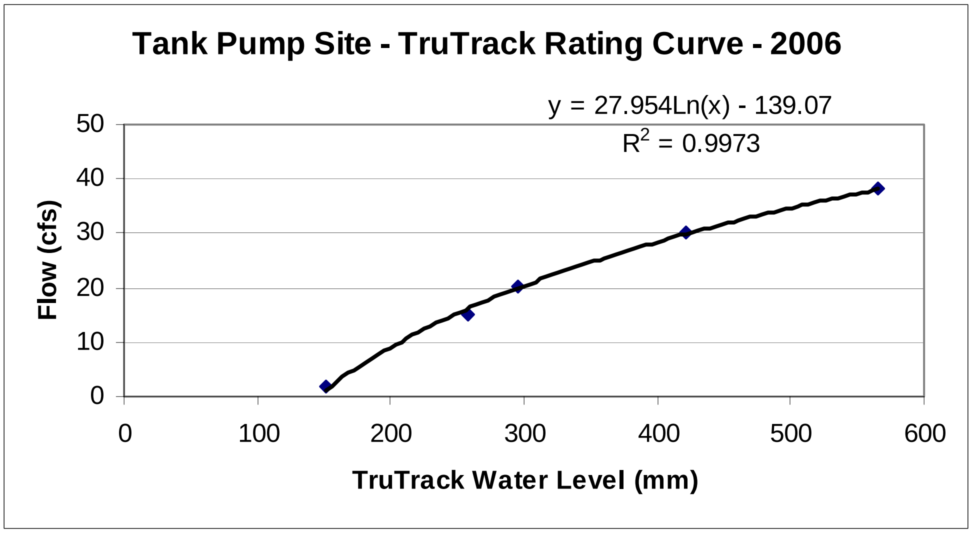

MC#2 - TruTrack Rating Curve - 2006
y = 0.0851x - 5.9026
R2 = 0.9845
Flow (cfs)
0
5
10
15
20
25
30
35
0
100
200
300
400
500
TruTrack Water Level (mm)

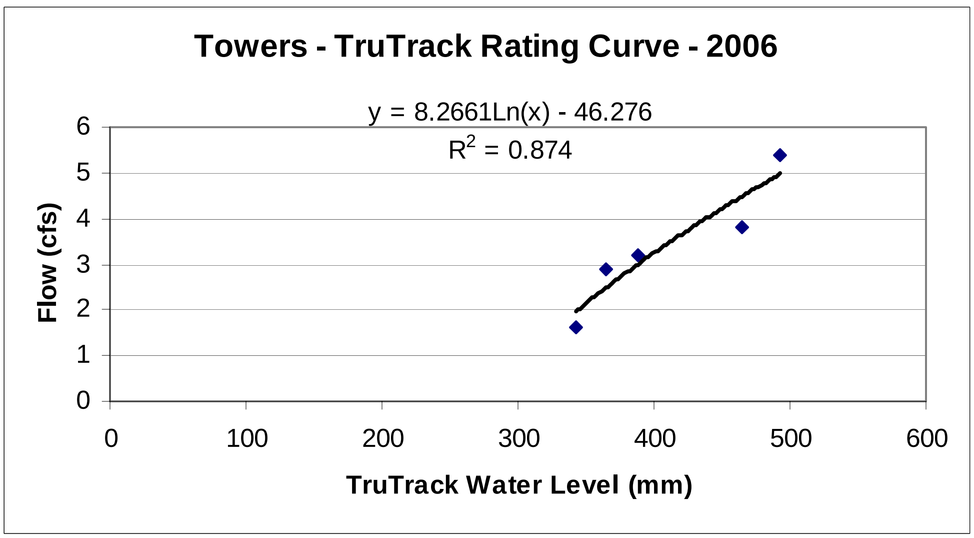

MC Trib at Sands - TruTrack Rating Curve
y = 17.027Ln(x) - 95.361
R2 = 0.9653
Flow (cfs)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
TruTrack Water Level (mm)

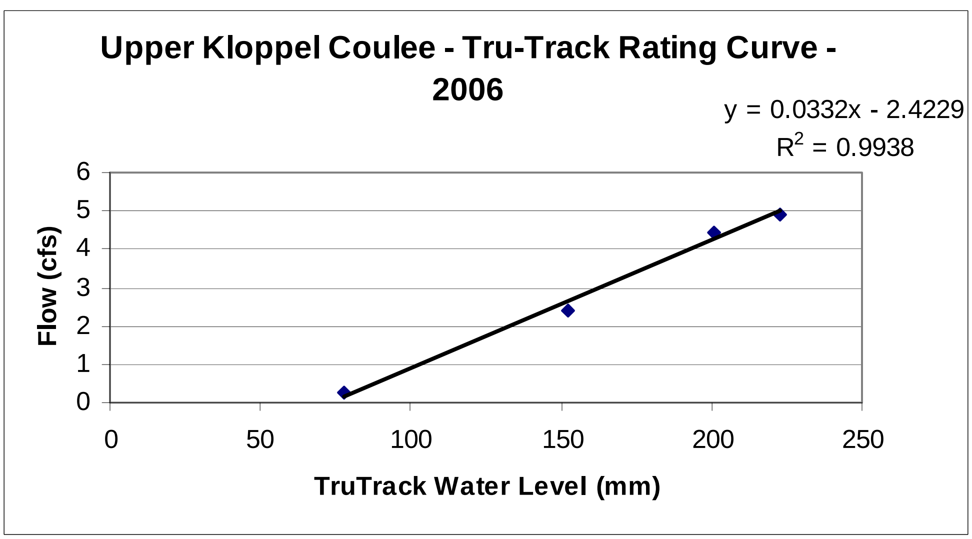

McAlpine - Aquarod Rating Curve - 2006
y = 0.0951e^0.017x
R^2 = 0.9962
Flow (cfs)
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Aquarod Water Level (mm)
if > 350 mm, linear curve used.

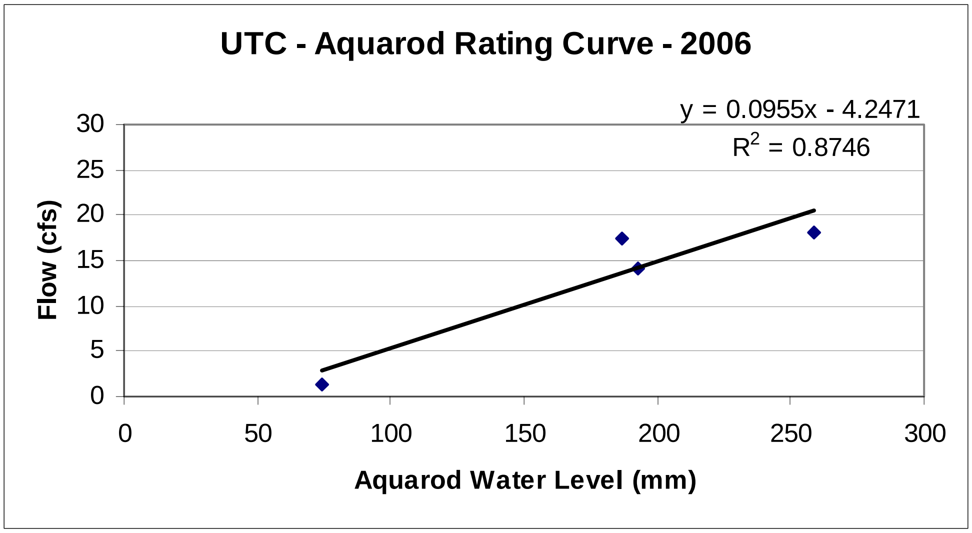

Middle Tank Coulee - Aquarod Rating Curve - 2006
y = 1E-20x^7.9147
R^2 = 0.8733
Flow (cfs)
60
50
40
30
20
10
0
440
460
480
500
520
540
560
Aquarod Water Level (mm)
if > 560 mm, linear trendline used.


Power - TruTrack Rating Curve - 2006
y = 0.1936x - 27.36
R^2 = 0.9946
Flow (cfs)
70
60
50
40
30
20
10
0
0
100
200
300
400
500
TruTrack Water Level (mm)


Tank Pump Site - TruTrack Rating Curve - 2006
y = 27.954Ln(x) - 139.07
R2 = 0.9973
Flow (cfs)
50
40
30
20
10
0
0
100
200
300
400
500
600
TruTrack Water Level (mm)

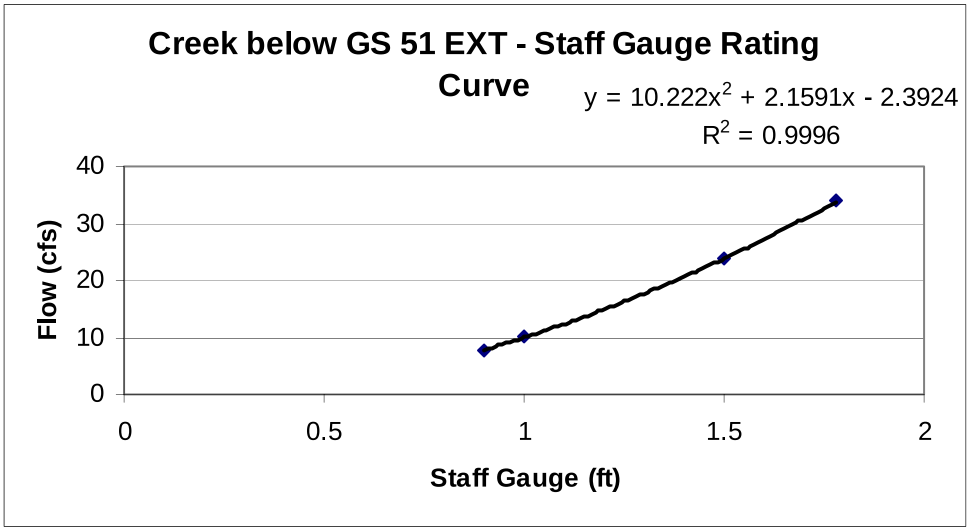

Towers - TruTrack Rating Curve - 2006
y = 8.2661Ln(x) - 46.276
R2 = 0.874
Flow (cfs)
6
5
4
3
2
1
0
0
100
200
300
400
500
600
TruTrack Water Level (mm)

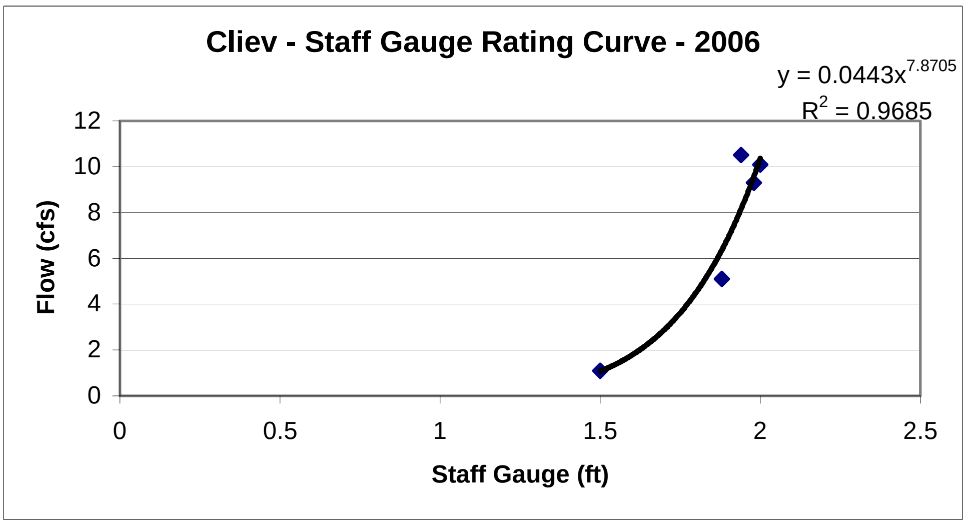

Upper Kloppel Coulee - Tru-Track Rating Curve - 2006
y = 0.0332x - 2.4229
R2 = 0.9938
Flow (cfs)
6
5
4
3
2
1
0
0
50
100
150
200
250
TruTrack Water Level (mm)

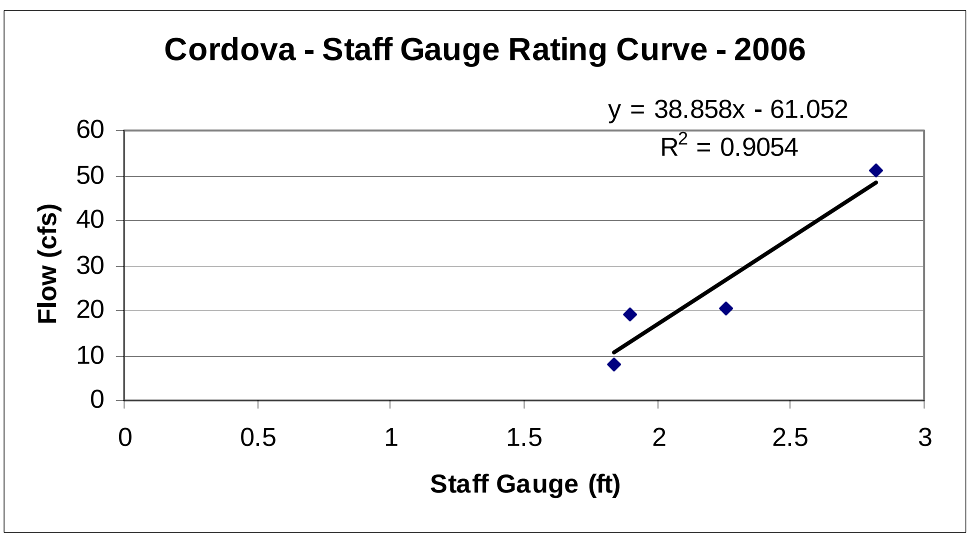


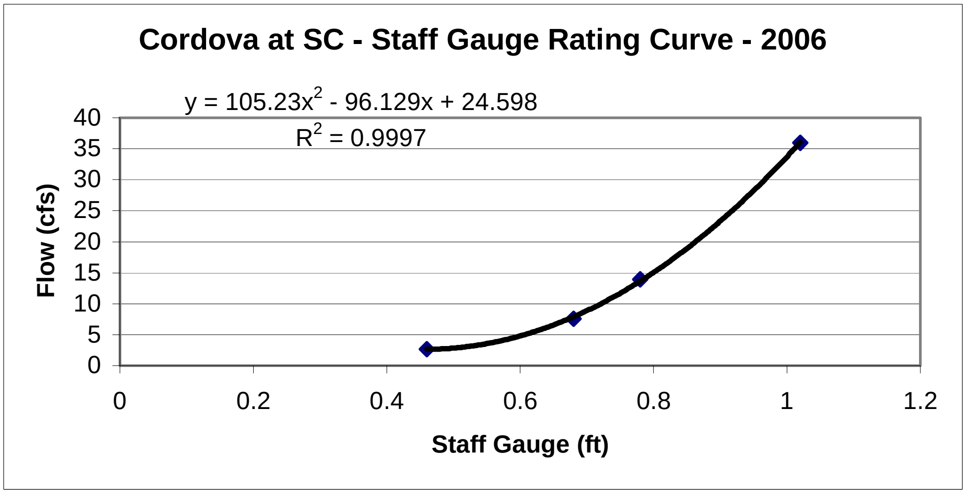
UTC - Aquarod Rating Curve - 2006
y = 0.0955x - 4.2471
R2 = 0.8746
Flow (cfs)
0
5
10
15
20
25
30
0
50
100
150
200
250
300
Aquarod Water Level (mm)

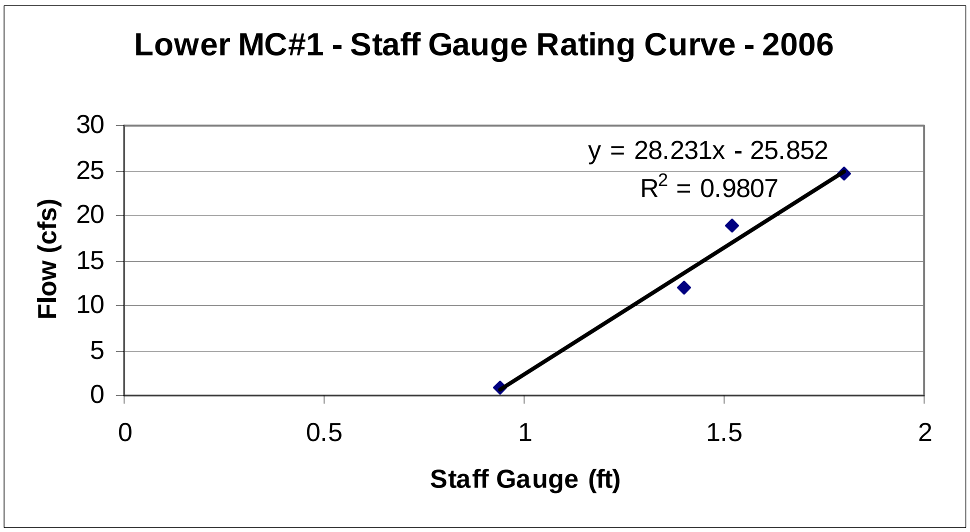
2. Staff Gauge Rating Curves

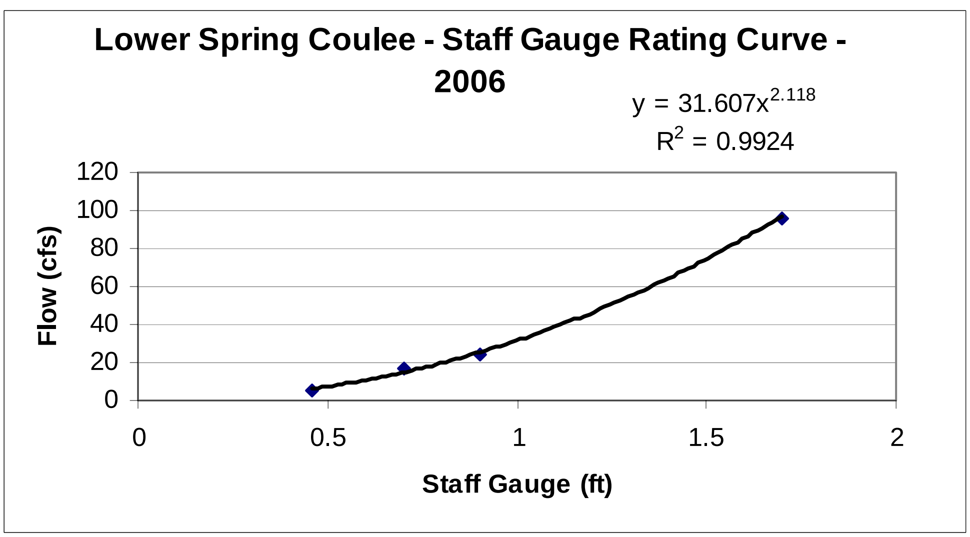


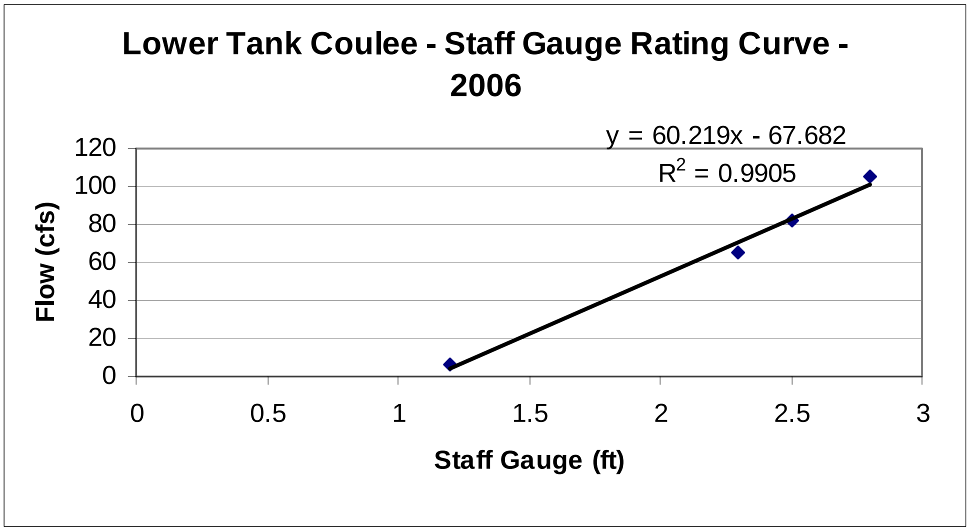


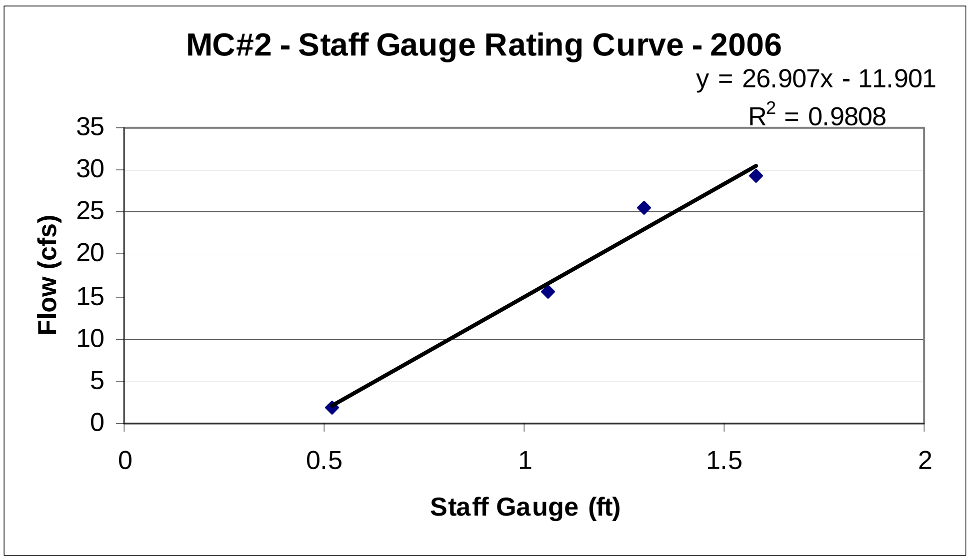


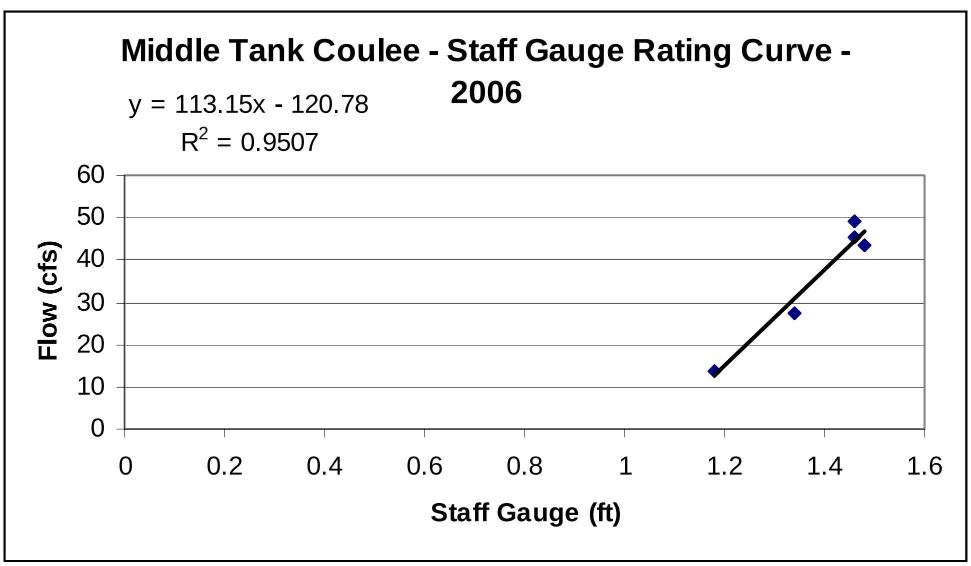

Cordova at SC - Staff Gauge Rating Curve - 2006
y = 105.23x2 - 96.129x + 24.598
R2 = 0.9997
Flow (cfs)
40
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
Staff Gauge (ft)

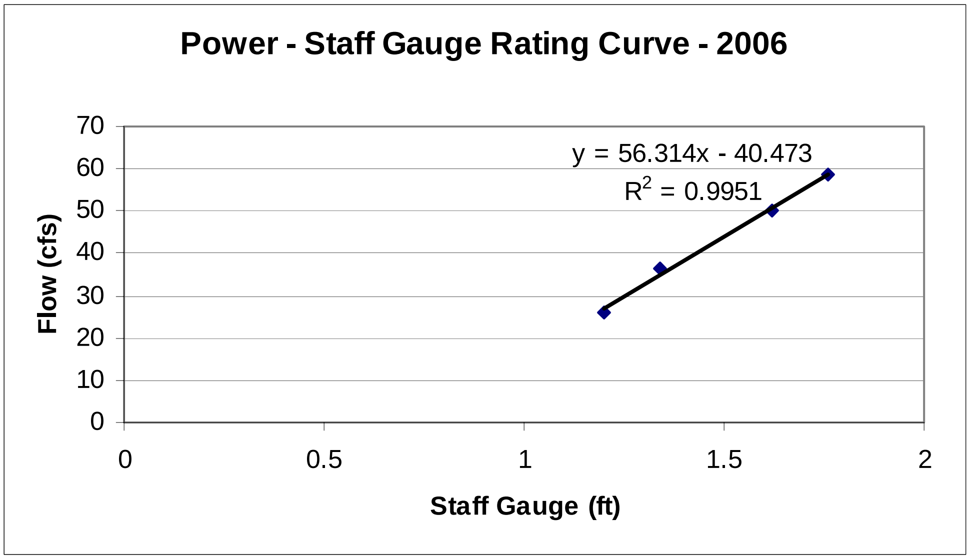

Lower MC#1 - Staff Gauge Rating Curve - 2006
y = 28.231x - 25.852
R2 = 0.9807
Flow (cfs)
30
25
20
15
10
5
0
0
0.5
1
1.5
2
Staff Gauge (ft)

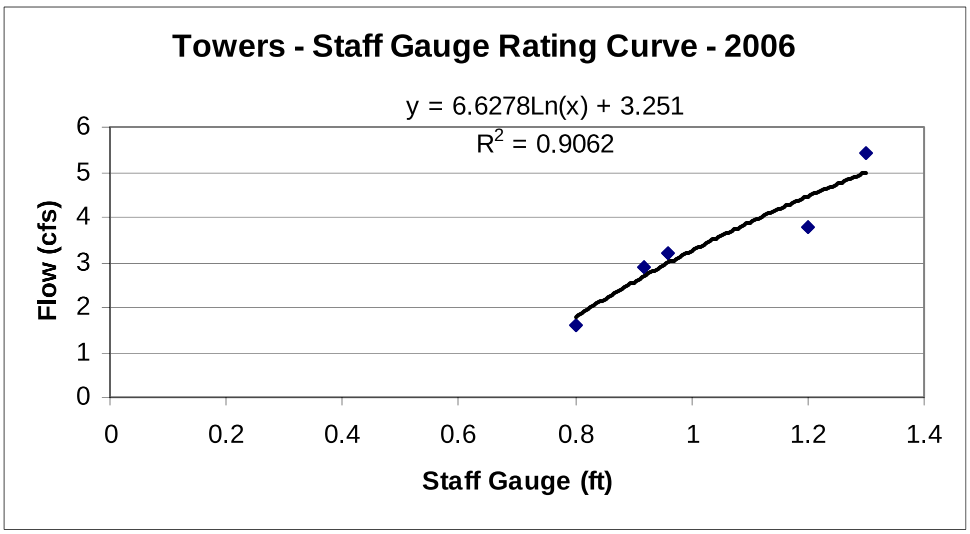

Lower Spring Coulee - Staff Gauge Rating Curve - 2006
y = 31.607x2.118
R2 = 0.9924
Flow (cfs)
120
100
80
60
40
20
0
0
0.5
1
1.5
2
Staff Gauge (ft)

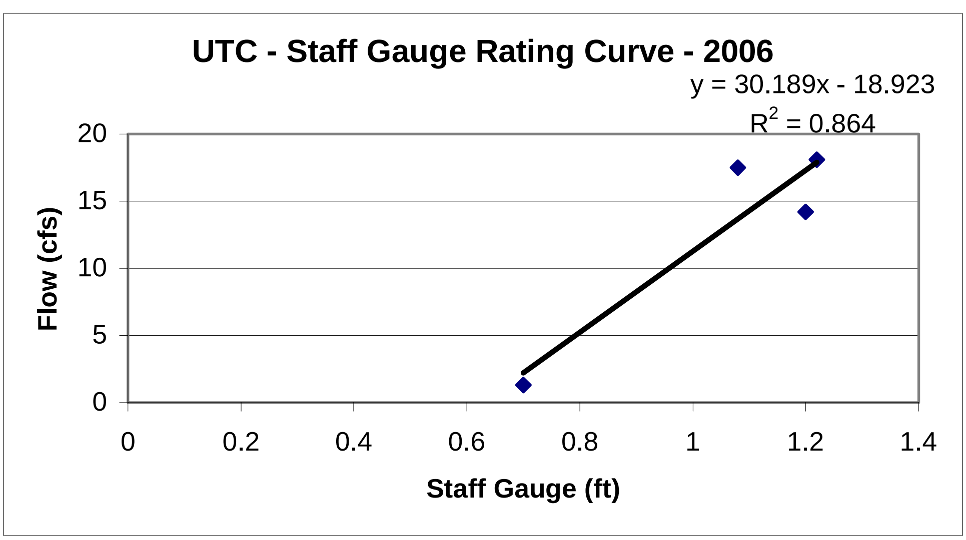

Lower Tank Coulee - Staff Gauge Rating Curve - 2006
y = 60.219x - 67.682
R2 = 0.9905
Flow (cfs)
0
20
40
60
80
100
120
0
0.5
1
1.5
2
2.5
3
Staff Gauge (ft)


MC#2 - Staff Gauge Rating Curve - 2006
y = 26.907x - 11.901
R2 = 0.9808
Flow (cfs)
0
5
10
15
20
25
30
35
0
0.5
1
1.5
2
Staff Gauge (ft)

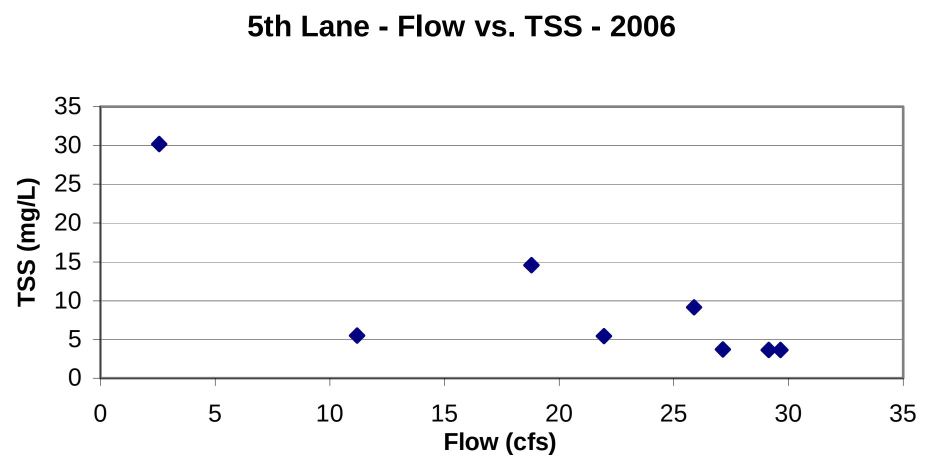

Middle Tank Coulee - Staff Gauge Rating Curve - 2006
y = 113.15x - 120.78
R2 = 0.9507
Flow (cfs)
0
10
20
30
40
50
60
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Staff Gauge (ft)


Power - Staff Gauge Rating Curve - 2006
y = 56.314x - 40.473
R2 = 0.9951
Flow (cfs)
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
Staff Gauge (ft)

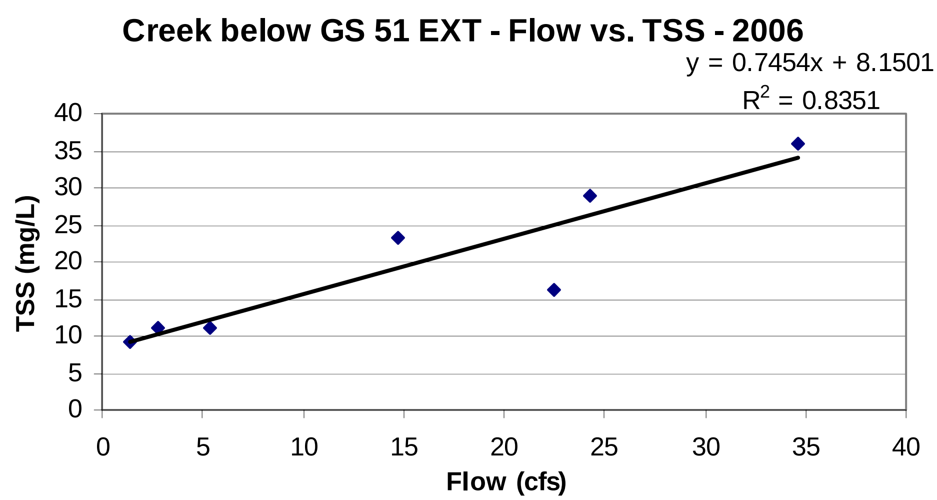

Towers - Staff Gauge Rating Curve - 2006
y = 6.6278Ln(x) + 3.251
R2 = 0.9062
Flow (cfs)
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Staff Gauge (ft)


UTC - Staff Gauge Rating Curve - 2006
y = 30.189x - 18.923
R2 = 0.864
Flow (cfs)
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Staff Gauge (ft)

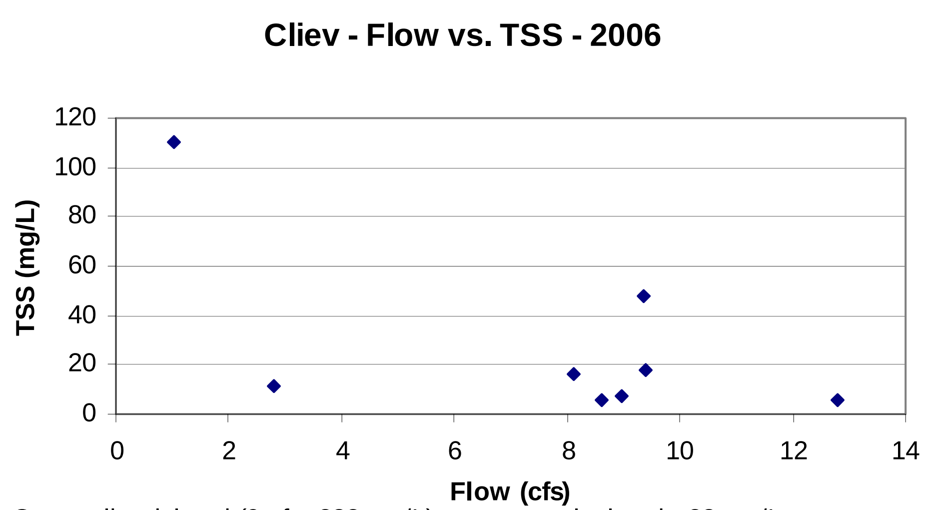
3. Flow vs. TSS Rating Curves



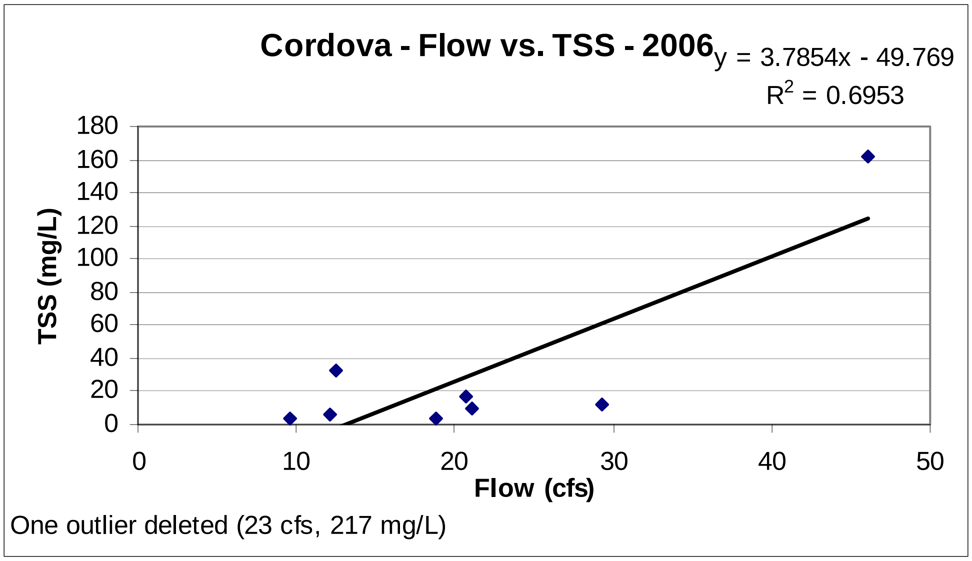
One outlier deleted (12 cfs, 110 mg/L), average calculated - 9 mg/L

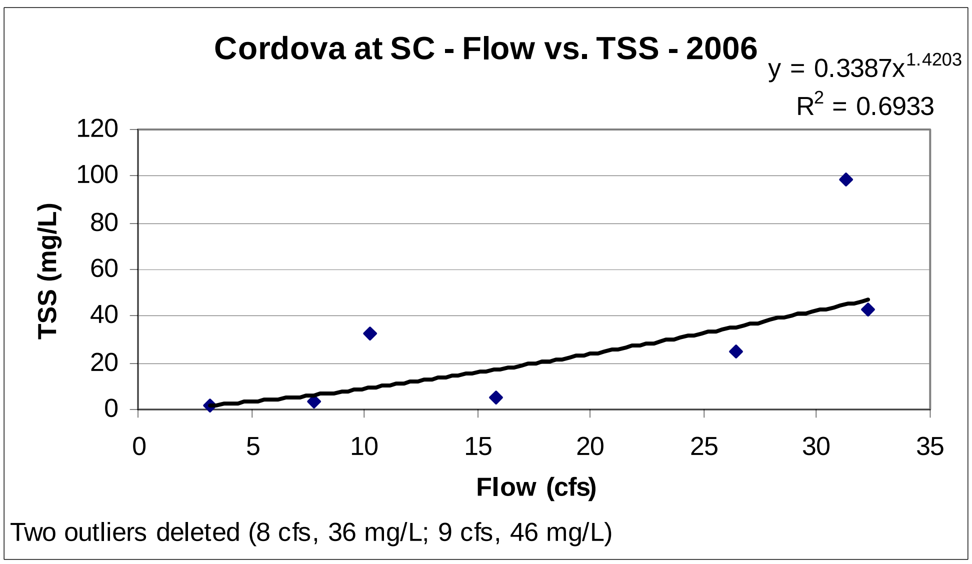


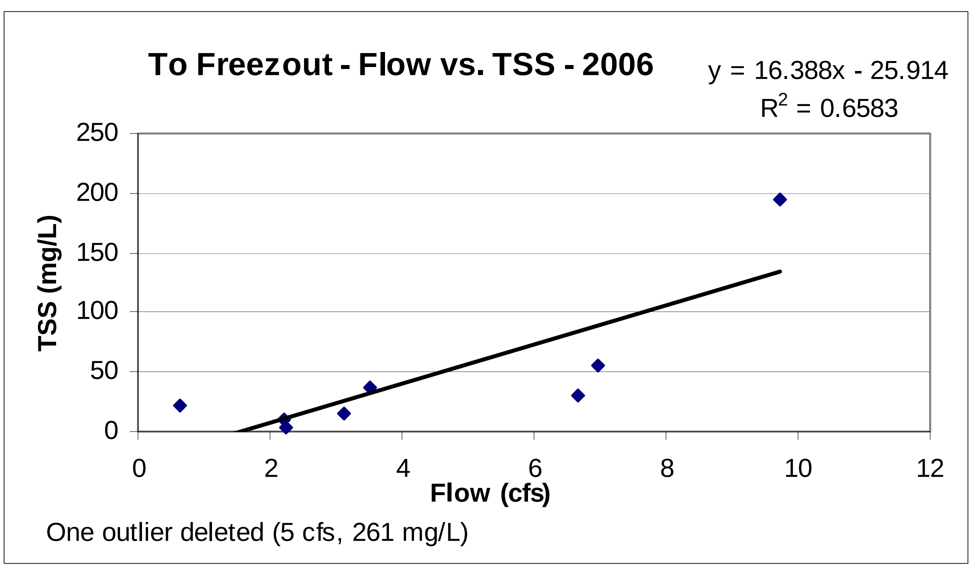
Two outliers deleted (6 cfs, 150 mg/L; 8 cfs, 42 mg/L)

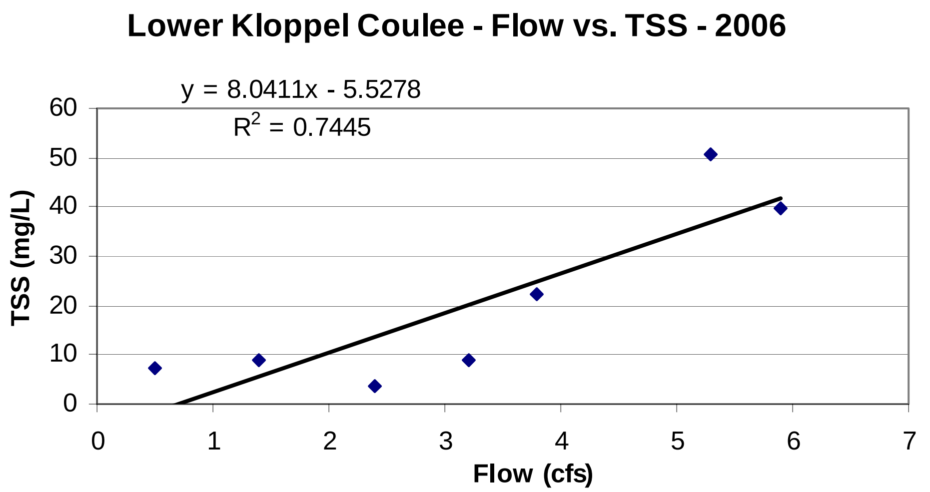


One outlier deleted (9 cfs, 283 mg/L), average calculated - 28 mg/L

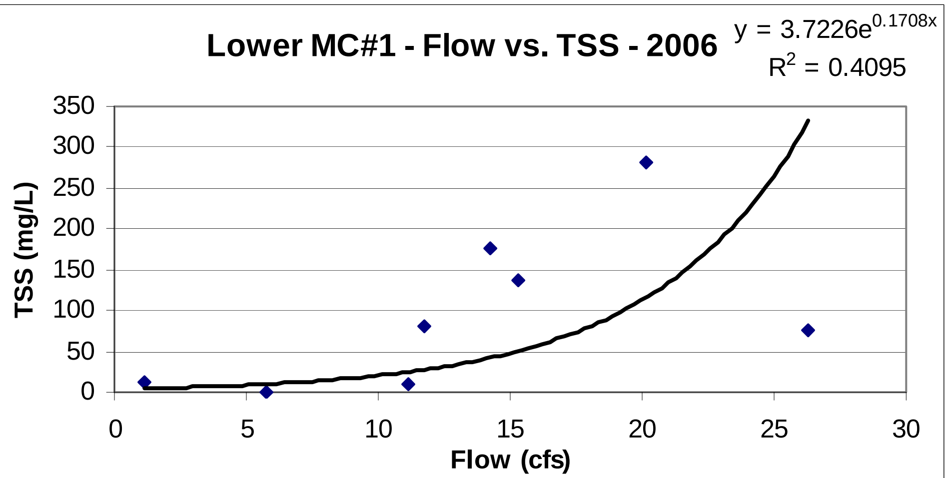

Cordova - Flow vs. TSS - 2006
y = 3.7854x - 49.769
R2 = 0.6953
TSS (mg/L)
Flow (cfs)
One outlier deleted (23 cfs, 217 mg/L)


Cordova at SC - Flow vs. TSS - 2006
y = 0.3387x1.4203
R2 = 0.6933
TSS (mg/L)
Flow (cfs)
Two outliers deleted (8 cfs, 36 mg/L; 9 cfs, 46 mg/L)

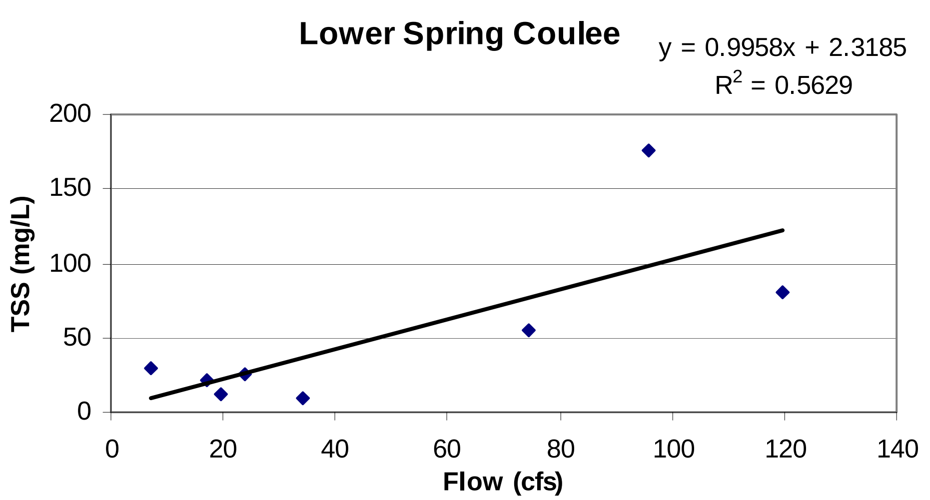

To Freezout - Flow vs. TSS - 2006
y = 16.388x - 25.914
R2 = 0.6583
TSS (mg/L)
Flow (cfs)
One outlier deleted (5 cfs, 261 mg/L)



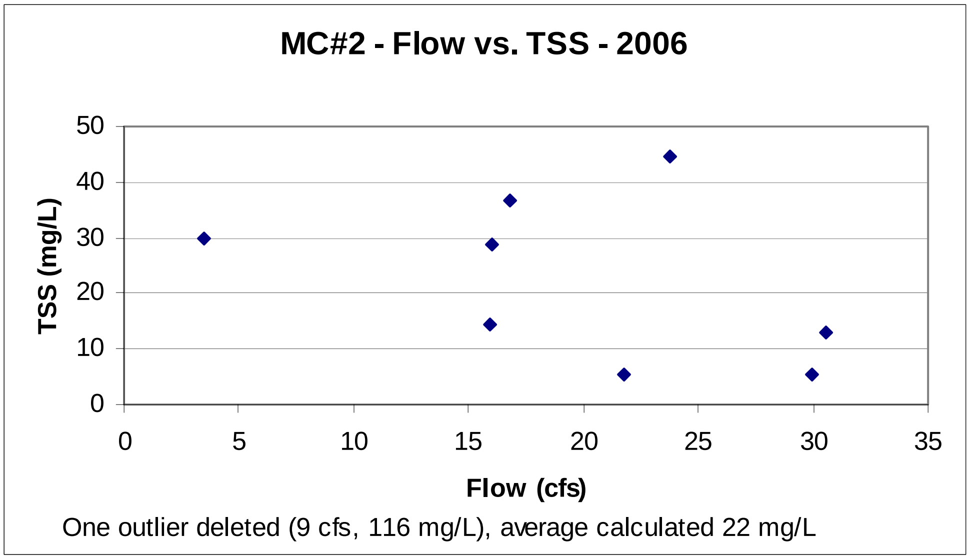
One outlier deleted (0.13 cfs, 25 mg/L)

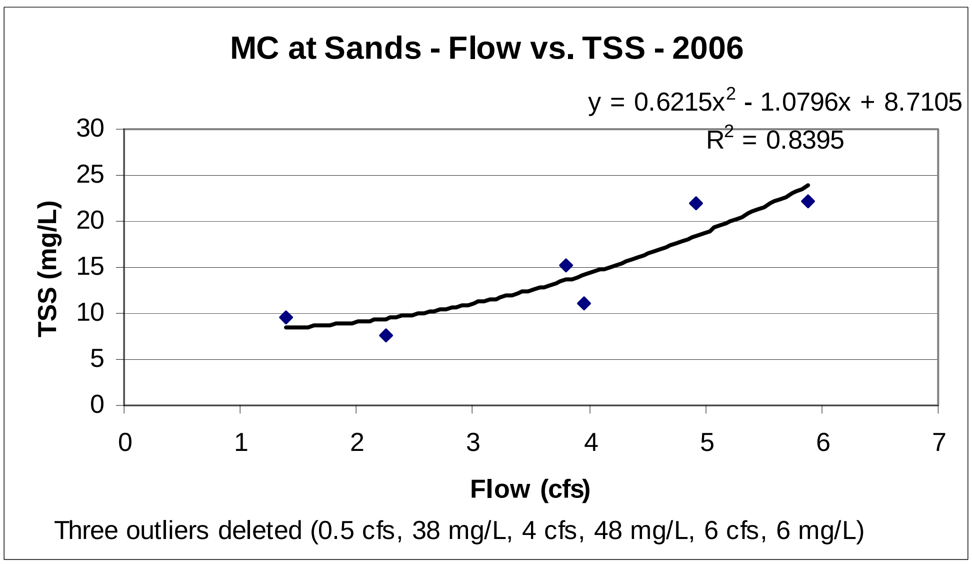


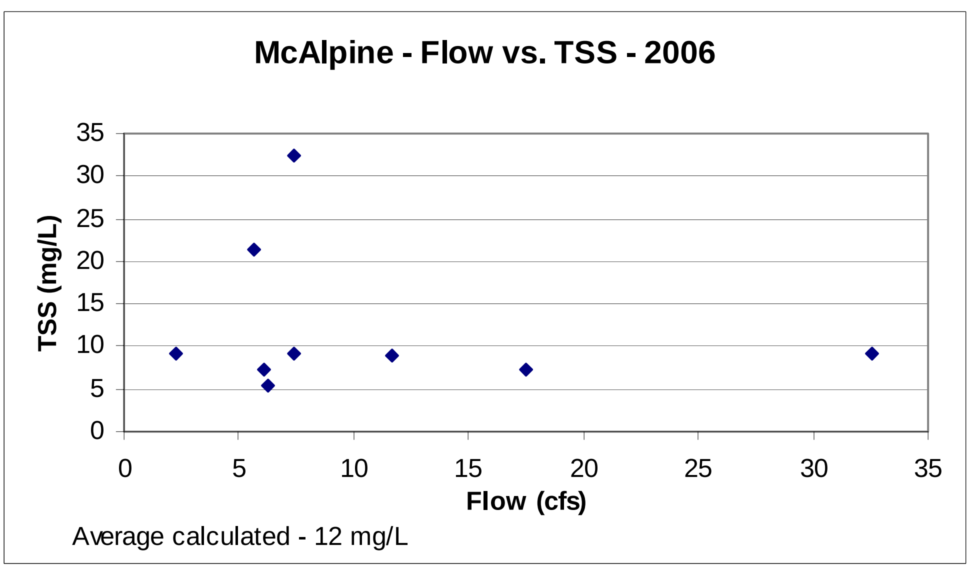
One outlier deleted (26 cfs, 27 mg/L),if flow greater than or equal to 25 cfs, then use linear flow vs. TSS rating curve

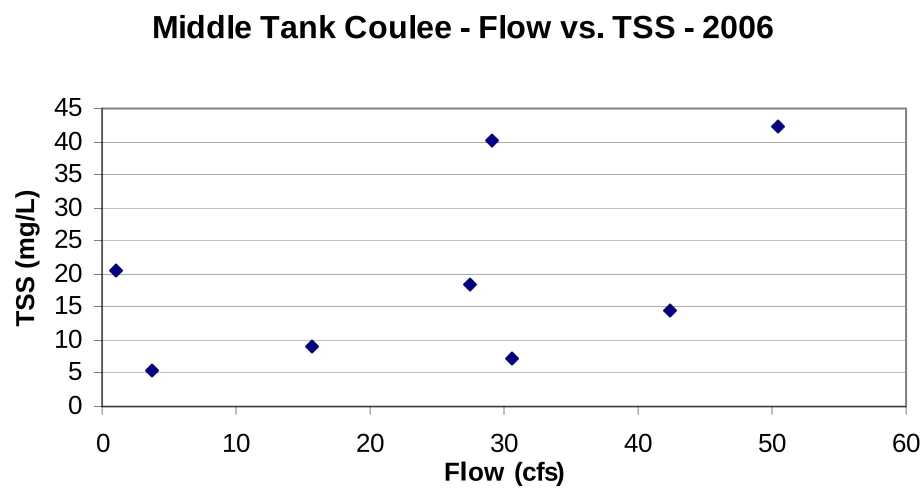


One outlier deleted (42 cfs, 160 mg/L)

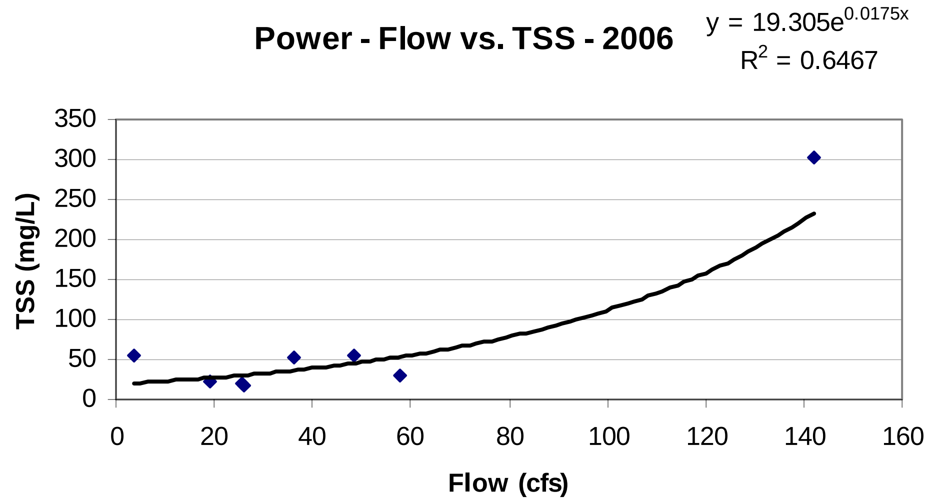

MC#2 - Flow vs. TSS - 2006
TSS (mg/L)
0
10
20
30
40
50
0
5
10
15
20
25
30
35
Flow (cfs)
One outlier deleted (9 cfs, 116 mg/L), average calculated 22 mg/L


MC at Sands - Flow vs. TSS - 2006
y = 0.6215x2 - 1.0796x + 8.7105
R2 = 0.8395
TSS (mg/L)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
Flow (cfs)
Three outliers deleted (0.5 cfs, 38 mg/L, 4 cfs, 48 mg/L, 6 cfs, 6 mg/L)

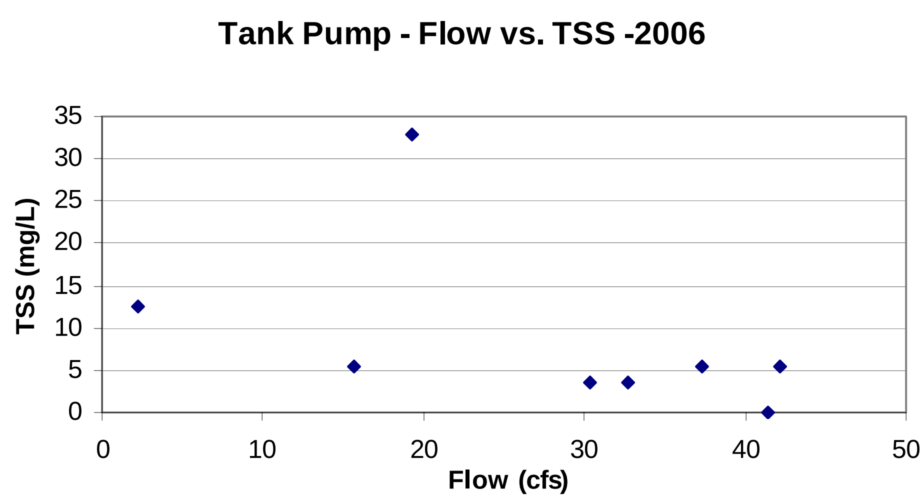

McAlpine - Flow vs. TSS - 2006
TSS (mg/L)
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
35
Flow (cfs)
Average calculated - 12 mg/L



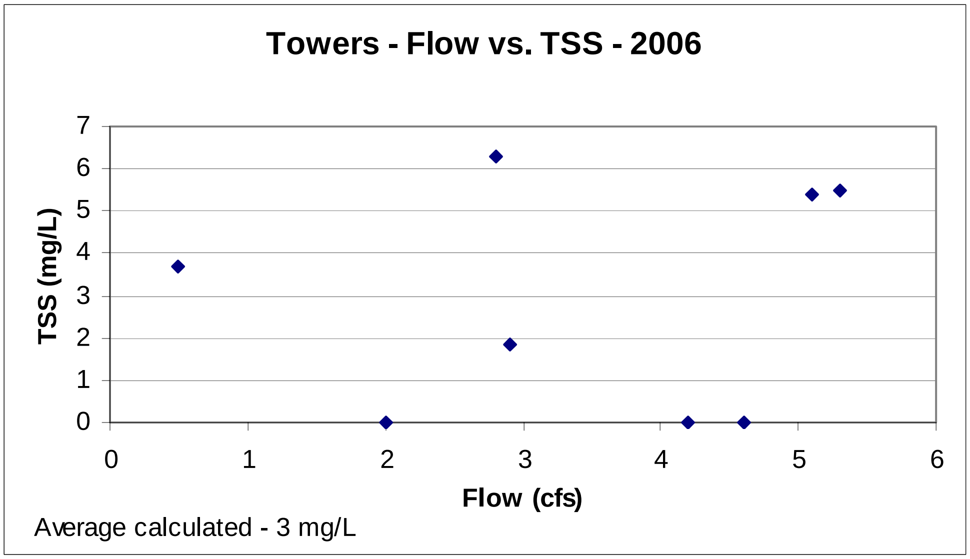
One outlier deleted (3 cfs, 128 mg/L), average calculated - 20 mg/L

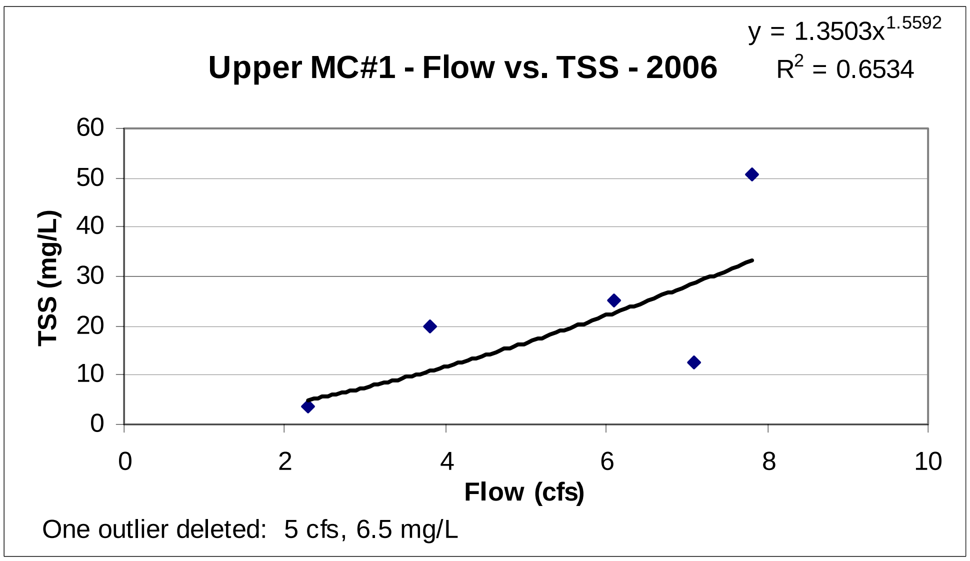


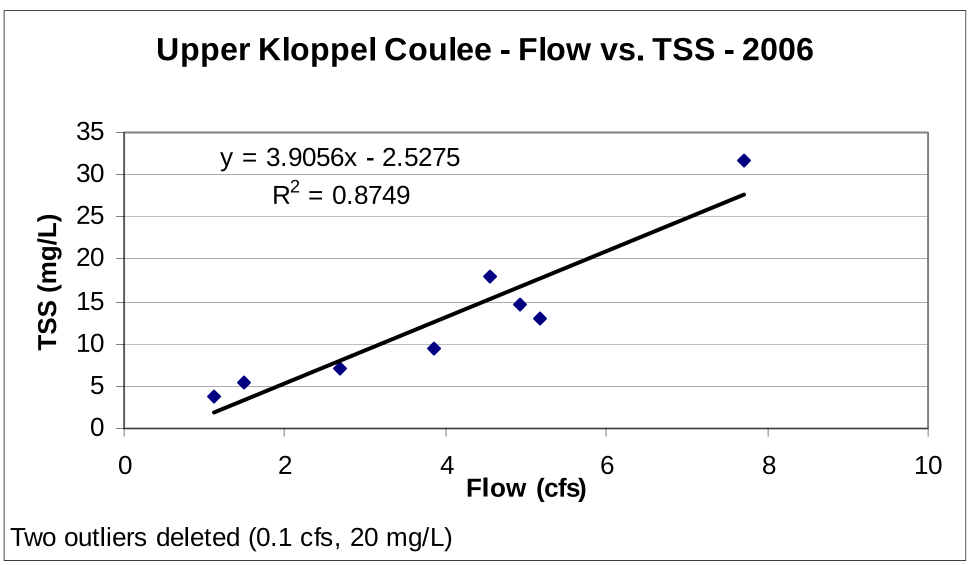
One outlier deleted (25 cfs, 338 mg/L)

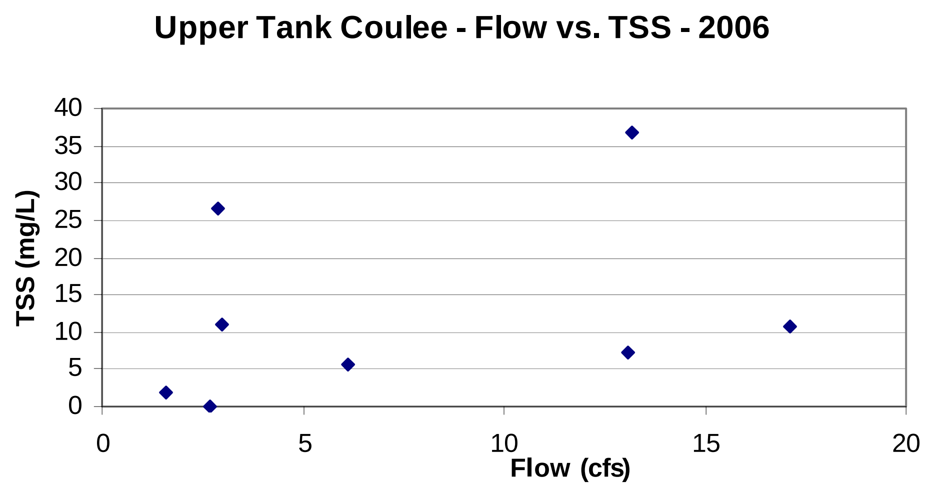


One outlier deleted (16 cfs, 125 mg/L), average calculated - 9 mg/L


Towers - Flow vs. TSS - 2006
TSS (mg/L)
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
Flow (cfs)
Average calculated - 3 mg/L


Upper MC#1 - Flow vs. TSS - 2006
y = 1.3503x^1.5592
R^2 = 0.6534
TSS (mg/L)
0
10
20
30
40
50
60
0
2
4
6
8
10
Flow (cfs)
One outlier deleted: 5 cfs, 6.5 mg/L


Upper Kloppel Coulee - Flow vs. TSS - 2006
y = 3.9056x - 2.5275
R^2 = 0.8749
TSS (mg/L)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
Flow (cfs)
Two outliers deleted (0.1 cfs, 20 mg/L)



One outlier deleted (4 cfs, 119 mg/L), average calculated - 12 mg/L